CARNEGIE INSTITUTION OF WASHINGTON

YEAR BOOK No. 45

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CARNEGIE INSTITUTION OF WASHINGTON
WASHINGTON, D. C.
1946

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PRESIDENT AND TRUSTEES

PRESIDENT

VANNEVAR BUSH

BOARD OF TRUSTEES

WALTER S. GIFFORD, *Chairman*
ELIHU ROOT, JR., *Vice-Chairman*
FREDERIC A. DELANO, *Secretary*

*THOMAS BARBOUR	HERBERT HOOVER	ELIHU ROOT, JR.
JAMES F. BELL	FRANK B. JEWETT	HENRY R. SHEPLEY
ROBERT WOODS BLISS	ERNEST O. LAWRENCE	RICHARD P. STRONG
LINDSAY BRADFORD	ALFRED L. LOOMIS	CHARLES P. TAFT
FREDERIC A. DELANO	ROSWELL MILLER	JUAN T. TRIPPE
HOMER L. FERGUSON	HENRY S. MORGAN	JAMES W. WADSWORTH
W. CAMERON FORBES	SEELEY G. MUDD	FREDERIC C. WALCOTT
WALTER S. GIFFORD	HENNING W. PRENTIS, JR.	LEWIS H. WEED
	GORDON S. RENTSCHLER	

Executive Committee

WALTER S. GIFFORD, *Chairman*

ROBERT WOODS BLISS	FREDERIC A. DELANO	FREDERIC C. WALCOTT
VANNEVAR BUSH	W. CAMERON FORBES	LEWIS H. WEED
	HENRY R. SHEPLEY	

Finance Committee

FREDERIC C. WALCOTT, *Chairman*

LINDSAY BRADFORD	HENNING W. PRENTIS, JR.
HENRY S. MORGAN	ELIHU ROOT, JR.

Auditing Committee

FREDERIC A. DELANO, *Chairman*

HOMER L. FERGUSON	JAMES W. WADSWORTH

STANDING COMMITTEES FOR THE YEAR 1946

Committee on Astronomy

HERBERT HOOVER, *Chairman*

ROSWELL MILLER	ELIHU ROOT, JR.
SEELEY G. MUDD	JUAN T. TRIPPE

Committee on Terrestrial Sciences

FRANK B. JEWETT, *Chairman*

HOMER L. FERGUSON	ALFRED L. LOOMIS
ERNEST O. LAWRENCE	FREDERIC C. WALCOTT

Committee on Biological Sciences

LEWIS H. WEED, *Chairman*

*THOMAS BARBOUR	HENNING W. PRENTIS, JR.
JAMES F. BELL	RICHARD P. STRONG
FREDERIC A. DELANO	

Committee on Historical Research

HENRY R. SHEPLEY, *Chairman*

ROBERT WOODS BLISS	CHARLES P. TAFT
RICHARD P. STRONG	JAMES W. WADSWORTH

* Deceased January 8, 1946.

FORMER PRESIDENTS AND TRUSTEES

PRESIDENTS

DANIEL COIT GILMAN, 1902–1904 ROBERT SIMPSON WOODWARD, 1904–1920
JOHN CAMPBELL MERRIAM, *President* 1921–1938; *President Emeritus* 1939–1945

TRUSTEES

ALEXANDER AGASSIZ	1904–05	SETH LOW	1902–16
GEORGE J. BALDWIN	1925–27	WAYNE MACVEAGH	1902–07
THOMAS BARBOUR	1934–46	ANDREW J. MELLON	1924–37
JOHN S. BILLINGS	1902–13	DARIUS O. MILLS	1902–09
ROBERT S. BROOKINGS	1910–29	S. WEIR MITCHELL	1902–14
JOHN L. CADWALADER	1903–14	ANDREW J. MONTAGUE	1907–35
WILLIAM W. CAMPBELL	1929–38	WILLIAM W. MORROW	1902–29
JOHN J. CARTY	1916–32	WILLIAM CHURCH OSBORN	1927–34
WHITEFOORD R. COLE	1925–34	JAMES PARMELEE	1917–31
CLEVELAND H. DODGE	1903–23	WM. BARCLAY PARSONS	1907–32
WILLIAM E. DODGE	1902–03	STEWARD PATON	1916–42
CHARLES P. FENNER	1914–24	GEORGE W. PEPPER	1914–19
SIMON FLEXNER	1910–14	JOHN J. PERSHING	1930–43
WILLIAM N. FREW	1902–15	HENRY S. PRITCHETT	1906–36
LYMAN J. GAGE	1902–12	ELIHU ROOT	1902–37
CASS GILBERT	1924–34	JULIUS ROSENWALD	1929–31
FREDERICK H. GILLETT	1924–35	MARTIN A. RYERSON	1908–28
DANIEL C. GILMAN	1902–08	THEOBALD SMITH	1914–34
JOHN HAY	1902–05	JOHN C. SPOONER	1902–07
MYRON T. HERRICK	1915–29	WILLIAM BENSON STOREY	1924–39
ABRAM S. HEWITT	1902–03	WILLIAM H. TAFT	1906–15
HENRY L. HIGGINSON	1902–19	WILLIAM S. THAYER	1929–32
ETHAN A. HITCHCOCK	1902–09	CHARLES D. WALCOTT	1902–27
HENRY HITCHCOCK	1902–02	HENRY P. WALCOTT	1910–24
WILLIAM WIRT HOWE	1903–09	WILLIAM H. WELCH	1906–34
CHARLES L. HUTCHINSON	1902–04	ANDREW D. WHITE	1902–03
WALTER A. JESSUP	1938–44	EDWARD D. WHITE	1902–03
SAMUEL P. LANGLEY	1904–06	HENRY WHITE	1913–27
CHARLES A. LINDBERGH	1934–39	GEORGE W. WICKERSHAM	1909–36
WILLIAM LINDSAY	1902–09	ROBERT S. WOODWARD	1905–24
HENRY CABOT LODGE	1914–24	CARROLL D. WRIGHT	1902–08

Besides the names enumerated above, the following were ex-officio members of the Board of Trustees under the original charter, from the date of organization until April 28, 1904: the President of the United States, the President of the Senate, the Speaker of the House of Representatives, the Secretary of the Smithsonian Institution, the President of the National Academy of Sciences.

STAFF OF INVESTIGATORS FOR THE YEAR 1946

ASTRONOMY

Mount Wilson Observatory

Pasadena, California

Organized in 1904; George E. Hale, Director 1904–1923, Honorary Director 1923–1936; Walter S. Adams, Director 1924–1945.

Ira S. Bowen, *Director*
Walter Baade
Harold D. Babcock
Horace W. Babcock
Theodore Dunham, Jr.
Joseph O. Hickox
Edison Hoge
Edwin P. Hubble
Milton L. Humason
Alfred H. Joy
Robert B. King
Paul W. Merrill
Rudolph Minkowski
Seth B. Nicholson
Edison Pettit
Robert S. Richardson
Roscoe F. Sanford
*Adriaan van Maanen
Olin C. Wilson
Ralph E. Wilson

TERRESTRIAL SCIENCES

Geophysical Laboratory

2801 Upton St., N.W., Washington 8, D. C.

Organized in 1906, opened in 1907; Arthur L. Day, Director 1909–1936

Leason H. Adams, *Director*
John S. Burlew
Joseph L. England
†Ralph E. Gibson
Roy W. Goranson
Joseph W. Greig
Earl Ingerson
Frank C. Kracek
†Orville H. Loeffler
George W. Morey
Charles S. Piggot
Eugene Posnjak
Howard S. Roberts
John F. Schairer
‡Earnest S. Shepherd
George Tunell
William D. Urry
Emanuel G. Zies

Department of Terrestrial Magnetism

5241 Broad Branch Road, N.W., Washington 15, D. C.

Organized in 1904; Louis A. Bauer, Director 1904–1929; John A. Fleming, Acting Director 1929–1934, Director 1935—June 30, 1946.

Merle A. Tuve, *Director*, July 1, 1946
Oliver H. Gish, *Assistant Director*
Philip H. Abelson
Lloyd V. Berkner
Edwin J. Chernosky
Dean B. Cowie
Scott E. Forbush
Albert A. Giesecke, Jr.
†George K. Green
†Lawrence R. Hafstad
Norman P. Heydenburg
Ellis A. Johnson
‡Henry F. Johnston
Mark W. Jones
Paul G. Ledig
†Alvin G. McNish
Wilfred C. Parkinson
Richard B. Roberts
William J. Roonfy
Walter E. Scott
Stuart L. Slaton
Kenneth L. Sherman
William F. Steiner
Oscar W. Torreson
Ernest H. Vestine
George R. Wait
Harry W. Wells
Francis W. Wood

* Deceased January 25, 1946.
† Resigned in 1946.
‡ Retired in 1946.

BIOLOGICAL SCIENCES

Division of Plant Biology

Central Laboratory, Stanford University, California

Desert Laboratory, opened in 1903, became headquarters of Department of Botanical Research in 1905. Name changed to Laboratory for Plant Physiology in 1923; reorganized in 1928 as Division of Plant Biology, including Ecology.

Herman A. Spoehr, *Chairman*
Jens C. Clausen
†Garrett J. Hardin
William M. Hiesey
David D. Keck
†Winston M. Manning
Harold W. Milner
James H. C. Smith
Harold H. Strain

Department of Embryology

Wolfe and Madison Streets, Baltimore 5, Maryland

Organized in 1914; Franklin P. Mall, Director 1914–1917; George L. Streeter, Director 1918–1940

George W. Corner, *Director*
Robert K. Burns
Louis B. Flexner
Chester H. Heuser, *Curator of the Embryological Collection*
‡Margaret R. Lewis
Samuel R. M. Reynolds
Walter S. Wilde

Department of Genetics

Cold Spring Harbor, Long Island, New York

Station for Experimental Evolution, opened in 1904, combined with Eugenics Record Office in 1921 to form Department of Genetics. Charles B. Davenport, Director 1904–1934; Albert F. Blakeslee, Director 1935–1941.

Milislav Demerec, *Director*
†Ugo Fano
Berwind P. Kaufmann
Edwin C. MacDowell
Barbara McClintock
Margaret R. McDonald

Research Associates

†John J. Biesele
Howard B. Newcombe
†S. G. Stephens

HISTORICAL RESEARCH

Division of Historical Research

10 Frisbie Place, Cambridge 38, Massachusetts

Department of Historical Research organized in 1903; Andrew C. McLaughlin, Director 1903–1905; J. Franklin Jameson, Director 1905–1928. In 1930 this Department was incorporated as a section of United States history in a new Division of Historical Research.

Alfred V. Kidder, *Chairman*
Elfanor B. Adams
Robert S. Chamberlain
Margaret W. Harrison, *Editor*
Sylvanus G. Morley
Earl H. Morris
Alexander Pogo
Harry E. D. Pollock
Tatiana Proskouriakoff
Ralph L. Roys
Karl Ruppert
George Sarton
†France V. Scholes
Anna O. Shepard
Edwin M. Shook
A. Ledyard Smith
Robert E. Smith
Gustav Strömsvik
Sol Tax
J. Eric S. Thompson
Alfonso Villa R.

† Resigned in 1946.
‡ Retired in 1946.

RESEARCH ASSOCIATES

Research Associates Engaged in Post-Retirement Studies

Walter S. Adams, Astronomy
Herbert E. Merwin, Geophysics
Frederick H. Seares, Astronomy
George L. Streeter, Embryology

Research Associates Connected with Other Institutions

V. Bjerknes (University of Oslo), Meteorology
Joseph C. Boyce (New York University), Physics
Ralph W. Chaney (University of California), Paleobotany
A. H. Compton (Washington University), Physics
Th. Dobzhansky (Columbia University), Genetics
Arthur T. Hertig (Boston Lying-in Hospital), Embryology
Victor F. Hess (Fordham University), Physics
Thomas H. Johnson (Bartol Research Foundation), Physics
S. A. Korff (New York University), Physics
E. A. Lowe (The Institute for Advanced Study), Paleography
Robert A. Millikan (California Institute of Technology), Physics
Robert Redfield (University of Chicago), Anthropology
France V. Scholes (University of New Mexico), History
Joel Stebbins (University of Wisconsin), Astronomy

OFFICES OF ADMINISTRATION

Office of the President

VANNEVAR BUSH, *President*
WALTER M. GILBERT, *Executive Officer*
SAMUEL CALLAWAY, *President's Secretary*

Office of Publications and Public Relations

FREDERICK G. FASSETT, JR., *Director*
AILENE J. BAUER, *Assistant to the Director*
DOROTHY R. SWIFT, *Editor*

Adviser on International Scientific Relations

JOHN A. FLEMING

Office of the Bursar

EARLE B. BIESECKER, *Bursar*
J. STANLEY LINGEBACH, *Assistant Bursar*

Investment Office (New York City)

PARKER MONROE, *Investment Officer*
RICHARD F. F. NICHOLS, *Assistant Investment Officer*

ORGANIZATION, PLAN, AND SCOPE

The Carnegie Institution of Washington was founded by Andrew Carnegie, January 28, 1902, when he gave to a board of trustees an endowment of registered bonds of the par value of ten million dollars. To this fund an addition of two million dollars was made by Mr. Carnegie on December 10, 1907, and a further addition of ten million dollars was made by him on January 19, 1911. Furthermore, the income of a reserve fund of about three million dollars, accumulated in accordance with the founder's specifications in 1911, is now available for general use, and in recent years a total of ten million dollars has been paid by the Carnegie Corporation of New York as increase to the Endowment Fund of the Institution. The Institution was originally organized under the laws of the District of Columbia and incorporated as the *Carnegie Institution,* articles of incorporation having been executed on January 4, 1902. The Institution was reincorporated, however, by an act of the Congress of the United States, approved April 28, 1904, under the title of the *Carnegie Institution of Washington.* (See existing Articles of Incorporation on following pages.)

Organization under the new Articles of Incorporation was effected May 18, 1904, and the Institution was placed under the control of a board of twenty-four trustees, all of whom had been members of the original corporation. The trustees meet annually in December to consider the affairs of the Institution in general, the progress of work already undertaken, and the initiation of new projects, and to make the necessary appropriations for the ensuing year. During the intervals between the meetings of the trustees the affairs of the Institution are conducted by an Executive Committee chosen by and from the Board of Trustees and acting through the President of the Institution as chief executive officer.

The Articles of Incorporation of the Institution declare in general "that the objects of the corporation shall be to encourage, in the broadest and most liberal manner, investigation, research, and discovery, and the application of knowledge to the improvement of mankind."

The Institution is essentially an operating organization. It attempts to advance fundamental research in fields not normally covered by the activities of other agencies, and to concentrate its attention upon specific problems, with the idea of shifting attack from time to time to meet the more pressing needs of research as they develop with increase of knowledge. Some of these problems require the collaboration of several investigators, special equipment, and continuous effort. Many close relations exist among activities of the Institution, and a type of organization representing investigations in astronomy, in terrestrial sciences, in biological sciences, and in historical research has been effected. Conference groups on various subjects have played a part in bringing new vision and new methods to bear upon many problems. Constant efforts are made to facilitate interpretation and application of results of research activities of the Institution, and an Office of Publications and Public Relations provides means for appropriate publication.

ARTICLES OF INCORPORATION

PUBLIC No. 260. An Act to incorporate the Carnegie Institution of Washington.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the persons following being persons who are now trustees of the Carnegie Institution, namely, Alexander Agassiz, John S. Billings, John L. Cadwalader, Cleveland H. Dodge, William N. Frew, Lyman J. Gage, Daniel C. Gilman, John Hay, Henry L. Higginson, William Wirt Howe, Charles L. Hutchinson, Samuel P. Langley, William Lindsay, Seth Low, Wayne MacVeagh, Darius O. Mills, S. Weir Mitchell, William W. Morrow, Ethan A. Hitchcock Elihu Root, John C. Spooner, Andrew D. White, Charles D. Walcott, Carroll D. Wright, their associates and successors, duly chosen, are hereby incorporated and declared to be a body corporate by the name of the Carnegie Institution of Washington and by that name shall be known and have perpetual succession, with the powers, limitations, and restrictions herein contained.

SEC. 2. That the objects of the corporation shall be to encourage, in the broadest and most liberal manner, investigation, research, and discovery, and the application of knowledge to the improvement of mankind; and in particular—

(a) To conduct, endow, and assist investigation in any department of science, literature, or art, and to this end to cooperate with governments, universities, colleges, technical schools, learned societies, and individuals.

(b) To appoint committees of experts to direct special lines of research.

(c) To publish and distribute documents.

(d) To conduct lectures, hold meetings, and acquire and maintain a library.

(e) To purchase such property, real or personal, and construct such building or buildings as may be necessary to carry on the work of the corporation.

(f) In general, to do and perform all things necessary to promote the objects of the institution, with full power, however, to the trustees hereinafter appointed and their successors from time to time to modify the conditions and regulations under which the work shall be carried on, so as to secure the application of the funds in the manner best adapted to the conditions of the time, provided that the objects of the corporation shall at all times be among the foregoing or kindred thereto.

SEC. 3. That the direction and management of the affairs of the corporation and the control and disposal of its property and funds shall be vested in a board of trustees, twenty-two in number, to be composed of the following individuals: Alexander Agassiz, John S. Billings, John L. Cadwalader, Cleveland H. Dodge, William N. Frew, Lyman J. Gage, Daniel C. Gilman, John Hay, Henry L. Higginson, William Wirt Howe, Charles L. Hutchinson, *Samuel P. Langley,* William Lindsay, Seth Low, Wayne MacVeagh, Darius O. Mills, S. Weir Mitchell, William W. Morrow, *Ethan A. Hitchcock,* Elihu Root, John C. Spooner, Andrew D. White, Charles D. Walcott, Carroll D. Wright, who shall constitute the first board of trustees. The board of trustees shall have power from time to time to increase its membership to not more than twenty-seven members. Vacancies occasioned by death, resignation, or otherwise shall be filled by the remaining trustees in such manner as the by-laws

shall prescribe; and the persons so elected shall thereupon become trustees and also members of the said corporation. The principal place of business of the said corporation shall be the city of Washington, in the District of Columbia.

SEC. 4. That such board of trustees shall be entitled to take, hold, and administer the securities, funds, and property so transferred by said Andrew Carnegie to the trustees of the Carnegie Institution and such other funds or property as may at any time be given, devised, or bequeathed to them, or to such corporation, for the purposes of the trust; and with full power from time to time to adopt a common seal, to appoint such officers, members of the board of trustees or otherwise, and such employees as may be deemed necessary in carrying on the business of the corporation, at such salaries or with such remuneration as they may deem proper; and with full power to adopt by-laws from time to time and such rules or regulations as may be necessary to secure the safe and convenient transaction of the business of the corporation; and with full power and discretion to deal with and expend the income of the corporation in such manner as in their judgment will best promote the objects herein set forth and in general to have and use all powers and authority necessary to promote such objects and carry out the purposes of the donor. The said trustees shall have further power from time to time to hold as investments the securities hereinafter referred to so transferred by Andrew Carnegie, and any property which has been or may be transferred to them or such corporation by Andrew Carnegie or by any other person, persons, or corporation, and to invest any sums or amounts from time to time in such securities and in such form and manner as are permitted to trustees or to charitable or literary corporations for investment, according to the laws of the States of New York, Pennsylvania, or Massachusetts, or in such securities as are authorized for investment by the said deed of trust so executed by Andrew Carnegie, or by any deed of gift or last will and testament to be hereafter made or executed.

SEC. 5. That the said corporation may take and hold any additional donations, grants, devises, or bequests which may be made in further support of the purposes of the said corporation, and may include in the expenses thereof the personal expenses which the trustees may incur in attending meetings or otherwise in carrying out the business of the trust, but the services of the trustees as such shall be gratuitous.

SEC. 6. That as soon as may be possible after the passage of this Act a meeting of the trustees hereinbefore named shall be called by Daniel C. Gilman, John S. Billings, Charles D. Walcott, S. Weir Mitchell, John Hay, Elihu Root, and Carroll D. Wright, or any four of them, at the city of Washington, in the District of Columbia, by notice served in person or by mail addressed to each trustee at his place of resi dence; and the said trustees, or a majority thereof, being assembled, shall organize and proceed to adopt by-laws, to elect officers and appoint committees, and generally to organize the said corporation; and said trustees herein named, on behalf of the corporation hereby incorporated, shall thereupon receive, take over, and enter into possession, custody, and management of all property, real or personal, of the corporation heretofore known as the Carnegie Institution, incorporated, as hereinbefore set forth under "An Act to establish a Code of Law for the District of Columbia, January fourth, nineteen hundred and two," and to all its rights, contracts, claims, and property of any kind or nature; and the several officers of such corporation, or

any other person having charge of any of the securities, funds, real or personal, books, or property thereof, shall, on demand, deliver the same to the said trustees appointed by this Act or to the persons appointed by them to receive the same; and the trustees of the existing corporation and the trustees herein named shall and may take such other steps as shall be necessary to carry out the purposes of this Act.

SEC. 7. That the rights of the creditors of the said existing corporation known as the Carnegie Institution shall not in any manner be impaired by the passage of this Act, or the transfer of the property hereinbefore mentioned, nor shall any liability or obligation for the payment of any sums due or to become due, or any claim or demand, in any manner or for any cause existing against the said existing corporation, be released or impaired; but such corporation hereby incorporated is declared to succeed to the obligations and liabilities and to be held liable to pay and discharge all of the debts, liabilities, and contracts of the said corporation so existing to the same effect as if such new corporation had itself incurred the obligation or liability to pay such debt or damages, and no such action or proceeding before any court or tribunal shall be deemed to have abated or been discontinued by reason of the passage of this Act.

SEC. 8. That Congress may from time to time alter, repeal, or modify this Act of incorporation, but no contract or individual right made or acquired shall thereby be divested or impaired.

SEC. 9. That this Act shall take effect immediately.

Approved, April 28, 1904

BY-LAWS OF THE INSTITUTION

Adopted December 13, 1904. Amended December 13, 1910, December 13, 1912, December 10, 1937, December 15, 1939, December 13, 1940, and December 18, 1942

ARTICLE I

THE TRUSTEES

1. The Board of Trustees shall consist of twenty-four members, with power to increase its membership to not more than twenty-seven members. The Trustees shall hold office continuously and not for a stated term.

2. In case any Trustee shall fail to attend three successive annual meetings of the Board he shall thereupon cease to be a Trustee.

3. No Trustee shall receive any compensation for his services as such.

4. All vacancies in the Board of Trustees shall be filled by the Trustees by ballot. Sixty days prior to an annual or a special meeting of the Board, the President shall notify the Trustees by mail of the vacancies to be filled and each Trustee may submit nominations for such vacancies. A list of the persons so nominated, with the names of the proposers, shall be mailed to the Trustees thirty days before the meeting, and no other nominations shall be received at the meeting except with the unanimous consent of the Trustees present. Vacancies shall be filled from the persons thus nominated, but no person shall be declared elected unless he receives the votes of two-thirds of the Trustees present.

ARTICLE II

MEETINGS

1. The annual meeting of the Board of Trustees shall be held in the City of Washington, in the District of Columbia, on the first Friday following the second Thursday of December in each year unless the date and place of meeting are otherwise ordered by the Executive Committee.

2. Special meetings of the Board may be called by the Executive Committee by notice served personally upon, or mailed to the usual address of, each Trustee twenty days prior to the meeting.

3. Special meetings shall, moreover, be called in the same manner by the Chairman upon the written request of seven members of the Board.

ARTICLE III

OFFICERS OF THE BOARD

1. The officers of the Board shall be a Chairman of the Board, a Vice-Chairman, and a Secretary, who shall be elected by the Trustees, from the members of the Board, by ballot to serve for a term of three years. All vacancies shall be filled by the Board for the unexpired term; provided, however, that the Executive Committee shall have power to fill a vacancy in the office of Secretary to serve until the next meeting of the Board of Trustees.

2. The Chairman shall preside at all meetings and shall have the usual powers of a presiding officer.

3. The Vice-Chairman, in the absence or disability of the Chairman, shall perform his duties.

4. The Secretary shall issue notices of meetings of the Board, record its transactions, and conduct that part of the correspondence relating to the Board and to his duties.

Article IV

EXECUTIVE ADMINISTRATION

The President

1. There shall be a President who shall be elected by ballot by, and hold office during the pleasure of, the Board, who shall be the chief executive officer of the Institution. The President, subject to the control of the Board and the Executive Committee, shall have general charge of all matters of administration and supervision of all arrangements for research and other work undertaken by the Institution or with its funds. He shall devote his entire time to the affairs of the Institution. He shall prepare and submit to the Board of Trustees and to the Executive Committee plans and suggestions for the work of the Institution, shall conduct its general correspondence and the correspondence with applicants for grants and with the special advisers of the Committee, and shall present his recommendations in each case to the Executive Committee for decision. All proposals and requests for grants shall be referred to the President for consideration and report. He shall have power to remove and appoint subordinate employees and shall be *ex officio* a member of the Executive Committee.

2. He shall be the legal custodian of the seal and of all property of the Institution whose custody is not otherwise provided for. He shall sign and execute on behalf of the corporation all contracts and instruments necessary in authorized administrative and research matters and affix the corporate seal thereto when necessary, and may delegate the performance of such acts and other administrative duties in his absence to the Executive Officer. He may execute all other contracts, deeds, and instruments on behalf of the corporation and affix the seal thereto when expressly authorized by the Board of Trustees or Executive Committee. He may, within the limits of his own authorization, delegate to the Executive Officer authority to act as custodian of and affix the corporate seal. He shall be responsible for the expenditure and disbursement of all funds of the Institution in accordance with the directions of the Board and of the Executive Committee, and shall keep accurate accounts of all receipts and disbursements. He shall submit to the Board of Trustees at least one month before its annual meeting in December a written report of the operations and business of the Institution for the preceding fiscal year with his recommendations for work and appropriations for the succeeding fiscal year, which shall be forthwith transmitted to each member of the Board.

3. He shall attend all meetings of the Board of Trustees.

4. There shall be an officer designated Executive Officer who shall be appointed by and hold office at the pleasure of the President, subject to the approval of the Executive Committee. His duties shall be to assist and act for the President as the latter may duly authorize and direct.

5. The President shall retire from office at the end of the calendar year in which he becomes sixty-five years of age.

Article V

COMMITTEES

1. There shall be the following standing Committees, *viz.* an Executive Committee, a Finance Committee, and an Auditing Committee.

2. The Executive Committee shall consist of the Chairman and Secretary of the Board of Trustees and the President of the Institution *ex officio* and, in addition, five trustees to be elected by the Board by ballot for a term of three years, who shall be eligible for re-election. Any member elected to fill a vacancy shall serve for the remainder of his predecessor's term: Provided, however, that of the Executive Committee first elected after the adoption of these by-laws two shall serve for one year, two shall serve for two years, and one shall serve for three years; and such Committee shall determine their respective terms by lot.

3. The Executive Committee shall, when the Board is not in session and has not given specific directions, have general control of the administration of the affairs of the corporation and general supervision of all arrangements for administration, research, and other matters undertaken or promoted by the Institution; shall appoint advisory committees for specific duties; shall determine all payments and salaries; and keep a written record of all transactions and expenditures and submit the same to the Board of Trustees at each meeting, and it shall also submit to the Board of Trustees a printed or typewritten report of each of its meetings, and at the annual meeting shall submit to the Board a report for publication. The Executive Committee shall have power to authorize the purchase, sale, exchange, or transfer of real estate.

4. The Executive Committee shall have general charge and control of all appropriations made by the Board.

5. The Finance Committee shall consist of five members to be elected by the Board of Trustees by ballot for a term of three years.

6. The Finance Committee shall have custody of the securities of the corporation and general charge of its investments and invested funds, and shall care for and dispose of the same subject to the directions of the Board of Trustees. It shall have power to authorize the purchase, sale, exchange, or transfer of securities and to delegate this power. It shall consider and recommend to the Board from time to time such measures as in its opinion will promote the financial interests of the Institution, and shall make a report at each meeting of the Board.

7. The Auditing Committee shall consist of three members to be elected by the Board of Trustees by ballot for a term of three years.

8. The Auditing Committee shall, before each annual meeting of the Board of Trustees, examine the accounts of business transacted under the Finance Committee and the Executive Committee. They may avail themselves at will of the services and examination of the Auditor appointed by the Board of Trustees. They shall report to the Board upon the collection of moneys to which the Institution is entitled, upon the investment and reinvestment of principal, upon the conformity of

expenditures to appropriations, and upon the system of bookkeeping, the sufficiency of the accounts, and the safety and economy of the business methods and safeguards employed.

9. All vacancies occurring in the Executive Committee and the Finance Committee shall be filled by the Trustees at the next regular meeting. In case of vacancy in the Finance Committee or the Auditing Committee, upon request of the remaining members of such committee, the Executive Committee may fill such vacancy by appointment until the next meeting of the Board of Trustees.

10. The terms of all officers and of all members of committees shall continue until their successors are elected or appointed.

Article VI

FINANCIAL STATEMENT

1. No expenditure shall be authorized or made except in pursuance of a previous appropriation by the Board of Trustees, or as provided in Article V, paragraph 6, hereof.

2. The fiscal year of the Institution shall commence on the first day of November in each year.

3. The Executive Committee, at least one month prior to the annual meeting in each year, shall cause the accounts of the Institution to be audited by a skilled accountant, to be appointed by the Board of Trustees, and shall submit to the annual meeting of the Board a full statement of the finances and work of the Institution and a detailed estimate of the expenditures of the succeeding year.

4. The Board of Trustees, at the annual meeting in each year, shall make general appropriations for the ensuing fiscal year; but nothing contained herein shall prevent the Board of Trustees from making special appropriations at any meeting.

5. The securities of the Institution and evidences of property, and funds invested and to be invested, shall be deposited in such safe depository or in the custody of such trust company and under such safeguards as the Trustees and Finance Committee shall designate; and the income available for expenditure of the Institution shall be deposited in such banks or depositories as may from time to time be designated by the Executive Committee.

6. Any trust company entrusted with the custody of securities by the Finance Committee may, by resolution of the Board of Trustees, be made Fiscal Agent of the Institution, upon an agreed compensation, for the transaction of the business coming within the authority of the Finance Committee.

Article VII

AMENDMENT OF BY-LAWS

1. These by-laws may be amended at any annual or special meeting of the Board of Trustees by a two-thirds vote of the members present, provided written notice of the proposed amendment shall have been served personally upon, or mailed to the usual address of, each member of the Board twenty days prior to the meeting.

ABSTRACT OF MINUTES OF THE FORTY-EIGHTH MEETING OF THE BOARD OF TRUSTEES

The meeting was held in Washington, D. C., in the Board Room of the Administration Building, on Friday, December 13, 1946. It was called to order at 10:30 A.M. by the Chairman, Mr. Gifford.

Upon roll call, the following Trustees responded: Robert Woods Bliss, Lindsay Bradford, Frederic A. Delano, Homer L. Ferguson, W. Cameron Forbes, Walter S. Gifford, Herbert Hoover, Frank B. Jewett, Ernest O. Lawrence, Alfred L. Loomis, Roswell Miller, Henry S. Morgan, Seeley G. Mudd, Henning W. Prentis, Jr., Elihu Root, Jr., Henry R. Shepley, Richard P. Strong, Charles P. Taft, Juan T. Trippe, James W. Wadsworth, Frederic C. Walcott, and Lewis H. Weed. The President of the Institution, Vannevar Bush, was also in attendance.

The minutes of the forty-seventh meeting were approved as printed and submitted to the members of the Board.

Reports of the President, the Executive Committee, the Auditor, the Finance Committee, the Auditing Committee, and of the Chairmen of Divisions, Directors of Departments, and Research Associates of the Institution were presented and considered.

The following appropriations for the year 1947 were authorized:

Pension Fund	$95,000
Administration (including expenses of Investment Office and of Insurance)	114,900
Expenses of Office of Publications and Public Relations	33,600
Departmental Research Operations	1,104,326
	$1,347,826

The Chairman reported the death of Thomas Barbour. As a result of balloting, Gordon S. Rentschler, Chairman of the National City Bank, New York, N. Y., was elected to fill the existing vacancy in the Board.

Henry S. Morgan was re-elected to continue service as a member of the Finance Committee for the unexpired term ending in 1948.

The meeting adjourned at 12:15 P.M.

REPORT OF THE EXECUTIVE COMMITTEE

For the Year Ending October 31, 1946

To the Trustees of the Carnegie Institution of Washington:

Gentlemen: Article V, section 3 of the By-Laws provides that the Executive Committee shall submit, at the annual meeting of the Board of Trustees, a report for publication; and Article VI, section 3 provides that the Executive Committee shall also submit, at the same time, a full statement of the finances and work of the Institution and a detailed estimate of the expenditures for the succeeding year. In accordance with these provisions, the Executive Committee herewith respectfully submits its report for the fiscal year ending October 31, 1946.

During this year the Executive Committee held five meetings, printed reports of which have been mailed to each Trustee and constitute a part of this report.

A statement of activities of the Institution is contained in the report of the President, which has been considered and approved by the Executive Committee, and is submitted herewith. All war research projects will have been terminated by the end of this year, and plans for postwar activities and for restatement of research objectives of much of the Institution's work are well under way.

The detailed estimate of expenditures for the succeeding year contained in the report of the President has been considered by the Executive Committee, which has approved the recommendations of the President in respect thereto and has provisionally approved the budget estimates based thereon and submitted therewith. The Executive Committee and the Finance Committee have given much consideration to the availability of funds for Institution activities in 1947 in the light of current economic conditions, and budget recommendations are based upon the judgment of these Committees in approving limited use of reserve funds to provide for emergency and terminating projects.

The Board of Trustees at its meeting of December 14, 1945, appointed Price, Waterhouse and Company to audit the accounts of the Institution for the fiscal year ending October 31, 1946. The report of the Auditor, including a balance sheet showing assets and liabilities of the Institution on October 31, 1946, is submitted as a part of the report of the Executive Committee.

In addition to the report of the Auditor there is also submitted a financial statement for the fiscal year ending October 31, 1946, showing funds available for expenditure and amounts allotted by the Executive Committee, a customary statement of receipts and disbursements since the organization of the Institution on January 28, 1902, and a schedule of real estate and equipment at original cost. These statements together with the tables in the Auditor's report comprise a full statement of the finances of the Institution.

A vacancy exists in the membership of the Board of Trustees by reason of the death in January 1946 of Thomas Barbour.

There are no vacancies in the membership of the Executive Committee, Finance Committee, or Auditing Committee.

WALTER S. GIFFORD, *Chairman*
ROBERT WOODS BLISS
VANNEVAR BUSH
FREDERIC A. DELANO
W. CAMERON FORBES
HENRY R. SHEPLEY
FREDERIC C. WALCOTT
LEWIS H. WEED

November 1, 1946

Financial Statement for Fiscal Year Ending October 31, 1946

	Balances unallotted Oct. 31, 1945	Trustees' appropriations Dec. 14, 1945	Transfers and other credits	Total available	Executive Committee allotments	Transfers by Executive Committee	Unallotted balances Oct. 31, 1946
Departmental Research Operations:							
Embryology		$90,718		$90,718.00	$90,718.00		
Genetics		118,060	$25,100.00	143,160.00	143,160.00		
Geophysical Laboratory		175,870	12,500.00	188,370.00	188,370 00		
Historical Research		138,603		138,603.00	138,603.00		
Mount Wilson Observatory		228,985	33,000.00	261,985.00	261,985 00		
Plant Biology		70,230		70,230.00	70,230.00		
Terrestrial Magnetism		239,900	38,000.00	277,900.00	277,900 00		
Research Projects of Limited Tenure	$5,732.65		4,657.90	10,390.55	9,400.00		$990.55
Publication	17,254.79	64,000	13,686.77	94,941.56	73,363.07		21,578.49
Administration		109,472	19,500.00	128,972.00	128,972.00		
Pension Fund		95,000		95,000.00	95,000.00		
General Contingent Fund	55,940 04		256,299.68	312,239.72	16,700 00	$234,000 00	61,539.72
Carnegie Corporation Emergency Fund	232,042.15		17,496 01	249,538.16	29,600.00	4,600 00	215,338.16
	$310,969.63	$1,330,838	$420,240.36	$2,062,047.99	$1,524,001.07	$238,600 00	$299,446.92

Aggregate Cash Receipts and Disbursements from Organization, January 28, 1902, to October 31, 1946

Receipts		Disbursements	
Securities Sold or Redeemed	$112,400,026.93	*Securities Purchased*	$127,916,629.66
Interest from Securities and Bank Balances	54,950,535 89	*Accrued Interest on Securities Purchased*	750,364.09
Sales of Publications	377,391.81	*Pension Fund*	1,745,440.08
Colburn Estate (Bequest)	52,015 74	*General Reserve Fund*	30,477.43
Harriman Fund (Sale of Land)	4,043.70	*Insurance Fund*	140,532.24
Teeple Estate (Bequest)	6,160.62	*Harriman Fund*	249.06
Carnegie Corporation of New York (Endowment Increase and for Specific Purposes)	13,693,381.24	*Harriet H. Mayor Relief Fund*	250.00
From Other Organizations and Individuals for Specific Purposes	445,563.55	*Special Emergency Reserve Fund*	63,819.41
Pension Fund (Refunds)	97,867.91	*National Defense Revolving Fund*	3,013,272.46
General Reserve Fund	64,746.81	*General Contingent Fund*	302,594.08
Insurance Fund (Refunds)	13,076 02	*Carnegie Corporation of New York Emergency Fund*	87,928 64
National Defense Revolving Fund (Refunds and Advances)	2,942,330.25	*Administration Building and Addition:*	
Administration Building Addition Account, Rentals and Refunds	18,021.09	Construction and Site (Old Building)	309,915.69
Employees' Salary Deductions for the Purchase of U. S. Bonds	84,943 40	Construction (Addition to Administration Bldg.)	416,206.07
Miscellaneous Refunds and Receipts	1.159,021.20	Site (Addition to Administration Building)	68,570.96
		Miscellaneous Expenditures*	40,825.37
		Departmental Research Operations:	
		Departments of Research, Buildings and Equipment	3,822,024.16
		Departmental Operations	34,951,403.95
		Research Projects of Limited Tenure	5,548,295.36
		Publication	2,988,220.16
		Administration	3,114,166.94
		Employees' U. S. Bond Purchases	84,518.15
		National Research Council	150,000.00
		Miscellaneous	9,008.82
			$185,554,712.78
		October 31, 1946, Cash in Banks	754,413.38
	$186,309,126 16		$186,309,126.16

* Includes Equipment $7,206.41, Repairs and Alterations to Old Building $18,599.29.

Real Estate and Equipment, Original Cost

Administration (October 31, 1946)		
1530 P Street, N.W., Washington, D. C.		
Building, site, and equipment		$848,508.95
Division of Plant Biology (September 30, 1946)		
Stanford University, California (Headquarters)		
Buildings and grounds	$74,125.72	
Laboratory	37,925 07	
Library	22,521 06	
Operating equipment	13,839.95	148,411.80
Department of Embryology (September 30, 1946)		
Wolfe and Madison Streets, Baltimore, Maryland		
Library	$7,474.40	
Laboratory	24,390.70	
Administration	8,148.05	40,013.15
Department of Genetics (September 30, 1946)		
Cold Spring Harbor, Long Island, New York		
Buildings, grounds, and field	$293,221 41	
Operating equipment	34,089.25	
Laboratory apparatus	44,812 56	
Library	61,449.31	
Archives	45,488 90	479,061.43
Geophysical Laboratory (September 30, 1946)		
2801 Upton Street, N.W., Washington, D. C.		
Building, library, and operating appliances	$292,819.93	
Laboratory apparatus	172,321.20	
Shop equipment	21,115.11	486,256.24
Division of Historical Research (September 30, 1946)		
10 Frisbie Place, Cambridge, Massachusetts		
Operating equipment	$30,599.35	
Library	15,839.55	46,438.90
Mount Wilson Observatory (September 30, 1946)		
Pasadena, California		
Buildings and grounds	$222,549.56	
Shop equipment	50,689 76	
Instruments	690,422.82	
Furniture and operating appliances	158,972.86	
Hooker 100-inch reflector	638,529.83	1,761,164 83
Department of Terrestrial Magnetism (September 30, 1946)		
5241 Broad Branch Road, N.W., Washington, D. C.		
Building, site, and office	$283,613.68	
Survey equipment	94,027.62	
Instruments, laboratory, and shop equipment	483,036.51	860,677 81
		$4,670,533.11

REPORT OF AUDITORS

To the Board of Trustees
Carnegie Institution of Washington
Washington, D. C.

We have made an examination of the attached balance sheet of Carnegie Institution of Washington (and supporting schedule of securities owned) as of October 31, 1946 and the related statement of operating income and expenditures for the fiscal year then ended. In connection therewith, we obtained confirmations from the custodian, Guaranty Trust Company of New York, as to the securities owned by the Institution and held in safekeeping at October 31, 1946 and from the depositaries as to the cash balances in banks at that date. The interest maturing during the fiscal year on bonds owned was accounted for, and the dividends received during the year on stocks owned were compared with published dividend records. With respect to a period of three months selected by us the recorded cash receipts were traced to deposits shown on the bank statements and paid checks and approved vouchers were inspected in support of the head office disbursements. We did not visit the branch offices of the Institution but we reviewed internal audit reports of the Bursar covering examinations of the branch records during the year and it appeared that the internal audits were satisfactorily conducted. We also inspected certified copies of the minutes of meetings of the Board of Trustees and the Executive Committee with respect to the appropriations and allotments for the year.

The securities are stated at cost, amortized cost or value at date acquired. In accordance with a recommendation made in February 1940 by the Institution's Finance Committee, premiums on bonds purchased subsequent to January 1, 1940 are being amortized on a straight-line basis to the dates on which the bonds are first callable or payable at par. The amortization of such premiums applicable to the year ended October 31, 1946 amounted to $8,314.61. Real estate and equipment are stated at cost, and books on hand for sale are carried at sales prices. In accordance with accepted practice no provision has been made for depreciation of property owned by the Institution.

In our opinion, with the foregoing explanations, the accompanying balance sheet and related statement of operating income and expenditures present fairly the position of Carnegie Institution of Washington at October 31, 1946 and the financial aspects of its operations for the year ended on that date.

PRICE, WATERHOUSE & CO.

Washington, D. C.
November 26, 1946

Balance Sheet October 31, 1946

Assets				Liabilities			
Investments:				*Endowment and Other Funds:*			
Securities		$40,152,345.19		Capital Funds:			
Cash:				Endowment Fund	$32,000,000.00		
Awaiting investment		163,884.09		Colburn Fund	103,310.80		
Reserved for current needs		135,670.75	$40,451,900.03	Capital Reserve Fund	5,493,700.96		
				Harriman Fund (excluding $179,628.05 included in Property Fund below)	362,842.42		
				Teeple Fund	6,160.62	$37,966,014.80	
				Special Funds:			
				Pension Fund	$192,133.66		
				Harriet H. Mayor Relief Fund	9,750.00		
				General Reserve Fund	1,834,001.57		
Property Account:				Current funds invested (see below)	450,000.00	2,485,885.23	$40,451,900.03
Real estate and equipment, at cost:				*Property Fund:*			
Office of Administration		$848,508.95		Income invested		$4,490,905.06	
Departments of research		3,822,024.16	4,670,533.11	Harriman property (gift)		179,628.05	4,670,533.11
				General Fund:			
				Current obligations and commitments:			
				Departmental research operations	$145,737.28		
				Research projects of limited tenure	10,954.65		
				Publication	72,053.07		
				Administration	22,674.29		
				General Contingent Fund	76,018.26		
				Carnegie Corporation Emergency Fund	235,705.39		
				Employees' U. S. Bond Purchase Fund	425.25		
				Annuity premium deposits and advances	340.27		
				Excess of advances received on U. S. Government contracts over disbursements made thereon	47,355.79		
				National Defense Revolving Fund (includes reimbursable expenditures of $148,023.47 from U. S. Government carried in accounts receivable, per contra)	300,000.00	$911,264.25	
				Unexpended and unallocated current income		226,672.46	
						$1,137,936.71	
				Less—Current funds invested (see above)		450,000.00	
						$687,936.71	
General Fund:				Value of publications and invoices		152,554.81	
Cash:				Publication paper in stock		94.83	840,586.35
General account	$454,858.54						
Departmental bank balances	62,910.28						
Petty cash and stamps	500.00	$518,268.82					
Accounts receivable due from U. S. Government (includes reimbursable expenditures of $148,023.47, per contra)		169,667.89					
Books on hand at sale price		152,041.25					
Outstanding accounts on sales of publications		513.56					
Paper in stock for future publications		94.83	840,586.35				
			$45,963,019.49				$45,963,019.49

General Fund

Statement of Operating Income and Expenditures for the Fiscal Year Ended October 31, 1946

Income:			
Interest and dividends on securities			$1,430,044.48
Less—Amortization of bond premiums			8,314.61
			$1,421,729.87
Appropriation from General Reserve Fund			20,000.00
Sales of publications			7,476.49
American Cancer Society—grants			6,314.17
Carnegie Corporation of New York—grants			13,000 00
Life Insurance Medical Research Fund—grant			1,000 00
State of Connecticut—contributions for survey			4,000 00
U. S. Public Health Service—grant			3,500 00
Proceeds from sale of Nutrition Laboratory			60,900.00
Other credits			5,382 41
			$1,543,302 94
Expenditures:			
Pension Fund—annuity and insurance		$124,136 78	
Harriet H. Mayor Relief Fund—benefits		250 00	
Carnegie Corporation Emergency Fund—grants		9,912 77	
Harriman Fund—commissions		45.78	
General Contingent Fund—miscellaneous expenses		9,967 08	
Departmental research operations:			
Salaries	$753,726 87		
Operating expenses	222,661 44	976,388.31	
Research projects of limited tenure:			
Salaries	$12,069.50		
Operating expenses	16,238 59	28,308 09	
General publication:			
Salaries	$1,864 67		
Operating expenses	15,504 10	17,368.77	
Office of publications:			
Salaries	$23,851.00		
Operating expenses	3,987.39	27,838 39	
Administration expenses		121,177.37	
		$1,315,393.34	
Less—Salaries and operating expenses charged to previous appropriations		271,109.92	1,044,283.42
Excess of income over expenditures			$499,019.52
Less—Credits to General Reserve Fund and other accounts			272,347.06
Unexpended and unallocated current income			$226,672.46

Schedule of Securities Owned October 31, 1946

Aggregate par or nominal value	Description	Maturity	Cost, amortized cost, or value at date acquired	Market value	Interest income for year
	United States Government Bonds				
$304,000	U. S. of America Treasury 2s	1951–49	$304,000.00	$311,315	$6,080.00
312,000	U. S. of America Treasury 2s	1951–49	312,000.00	319,605	6,240.00
200,000	U. S. of America Treasury 2s	1952–50	200,000.00	204,938	4,000.00
4,500,000	U. S. of America Treasury 2s	1954–52	4,500,000.00	4,629,375	90,000.00
800,000	U. S. of America Treasury 2¼s	1955–52	800,000.00	831,250	18,000.00
400,000	U. S. of America Treasury 2¼s	1959–56	427,570.00*	420,000	3,741.84
450,000	U. S. of America Treasury 2¼s	1962–59	462,044.19*	459,141	3,251.38
2,220,000	U. S. of America Treasury 2¼s	1962–59	2,221,753.17*	2,265,094	26,429.86
1,239,000	U. S. of America Treasury 2½s	1954–52	1,242,755.90*	1,301,337	30,975.00
350,000	U. S. of America Treasury 2½s	1967–62	350,000.00	366,844	8,750.00
1,200,000	U. S. of America Treasury 2½s	1969–64	1,200,000.00	1,246,875	30,000.00
400,000	U. S. of America Treasury 2½s	1969–64	400,000.00	415,375	10,000.00
300,000	U. S. of America Treasury 2½s	1972–67	309,330.50*	308,063	3,049.46
2,350,000	U. S. of America Treasury 2½s	1972–67	2,350,000.00	2,413,156	31,306.02
50,000	U. S. of America Savings Defense "G" 2½s	1953	50,000.00	47,600	1,250.00
50,000	U. S. of America Savings Defense "G" 2½s	1954	50,000.00	47,350	1,250.00
50,000	U. S. of America Savings Defense "G" 2½s	1954	50,000.00	47,350	1,250.00
100,000	U. S. of America Savings Defense "G" 2½s	1955	100,000.00	94,800	2,500.00
100,000	U. S. of America Savings Defense "G" 2½s	1956	100,000.00	95,600	2,500.00
100,000	U. S. of America Savings Defense "G" 2½s	1957	100,000.00	96,900	2,500 00
100,000	U. S. of America Savings Defense "G" 2½s	1958	100,000 00	98,800	1,250.00
	Income from bonds sold or redeemed				23,553.67
$15,575,000	Total U. S. Government		$15,629,453 76	$16,020,768	$307,877 23
	Foreign Bonds				
$100,000	Australia, Commonwealth of, S. F. 3¼s	1956	$100,000 00	$101,000	−$315 99
200,000	Canada, Dominion of, 8th Victory Loan 3s	1963	207,584.91*	200,000	1,318 41
450,000	Canada, Dominion of, 9th Victory Loan 3s	1966	428,625.00	445,500	7,144 05
90,000	Canadian National Ry. Co., 4½s Guar.	1951	90,182.95*	100,800	4,050 00
100,000	Canadian National Ry. Co., 4½s Guar.	1957	112,000 00	119,000	4,500 00
57,000	Canadian National Ry. Co., 5s Guar.	1969	61,522 20*	64,980	2,850 00
35,000	Canadian National Ry. Co., 5s Guar.	1970	37,648 85*	39,900	1,750 00
100,000	Canadian Pacific Railway Co., Perpetual Cons. Deb. 4s		88,158 33	105,000	4,000.00
100,000	Province of Nova Scotia Deb. 4½s	1952	100,312 50	102,000	4 500.00
200,000	Shawinigan Water and Power Co., 1st Mtg & Coll Tr. S. F. 3s	1971	208,820 00*	204,000	2,766 67
100,000	City of Toronto Cons. Loan Deb. 5s	1949	96,164 59	109,000	5,000 00
	Income from bonds called, exchanged, or sold				43,780 42
$1,532,000	Total Foreign		$1,531,019.33	$1,591,180	$81,343.56

* After deduction for amortization of premiums on bonds purchased subsequent to January 1, 1940.

SCHEDULE OF SECURITIES OWNED OCTOBER 31, 1946—*Continued*

Aggregate par or nominal value	Description	Maturity	Cost, amortized cost, or value at date acquired	Market value	Interest income for year
	PUBLIC UTILITY BONDS				
$243,000	Columbus & Southern Ohio Electric Co., 1st Mtg. 3¼s	1970	$258,425.66*	$264,870	$7,897.50
60,000	Detroit Edison Co., Gen. & Ref. Mtg. 4s	1965	62,100.00	64,800	2,400.00
200,000	Minnesota Power & Light Co., 1st Mtg. 3⅜s	1975	204,764.04*	212,000	6,250.00
100,000	Ohio Power Co., 1st Mtg. 3⅛s	1968	101,500.00	107,000	3,250.00
100,000	Oklahoma Natural Gas Co., 1st Mtg. 2⅞s	1961	101,340.62*	102,000	2,875.00
200,000	Public Service Co. of Indiana, Inc., 1st Mtg. 3⅛s	1975	204,769.25*	212,000	6,250.00
125,000	Puget Sound Power & Light Co., 1st Mtg. 4¼s	1972	129,704.44*	133,750	5,312.50
220,000	Tennessee Gas and Transmission Co., 1st Mtg. Pipe Line 2¾s	1966	223,217 50*	222,200	2,840.15
120,000	Toledo Edison Co., 1st Mtg. 3⅛s	1968	121,800.00	124,800	4,200.00
282,000	United Gas Corp., 1st Mtg. Coll. Tr. 3s	1962	282,000.00	282,000	8,460.00
	Income from bonds called, converted, or sold	....	....	.....	49,968.90
$1,650,000	Total Public Utility	.....	$1,689,621.51	$1,725,420	$99,704.05
	COMMUNICATION BONDS				
$52,000	New England Telephone & Telegraph Co., 1st Mtg. 5s	1952	$51,748.00	$56,680	$2,600.00
	Income from bonds called	.....	.....	.....	5,915.00
$52,000	Total Communications	.....	$51,748.00	$56,680	$8,515.00
	RAILROAD EQUIPMENT TRUSTS				
	Income from bonds sold	.....	.....	.....	$2,337.00
	RAILROAD BONDS				
$100,000	Chesapeake & Ohio Ry. Co., Gen. Mtg. 4½s	1992	$99,464.29	$137,000	$4,500.00
75,000	Chicago & W. Indiana R. R. Co., Cons. 4s	1952	70,357.66	79,500	3,000.00
200,000	Erie R. R. Co., 1st Cons. Mtg. 3½s	1990	201,256.25*	192,000	6,250.00
100,000	Great Northern Ry. Co., Gen. Mtg. 5s	1973	104,385.84	129,000	5,000.00
75,000	Pennsylvania R. R. Co., Gen. Mtg. 4½s	1965	75,918.75	85,500	3,375.00
100,000	Pennsylvania R. R. Co., Cons. Mtg. 4½s	1960	104,662.50	122,000	4,500.00
50,000	Pittsburgh, Cin., Chi. & St. L. R. R. Co., Gen. Mtg. 5s Guar.	1975	51,898.98	64,000	2,500.00
100,000	Southern Rwy. Co., 1st Cons. Mtg. 5s	1994	103,580.34	118,000	5,000.00
100,000	Toledo & Ohio Central Ry. Co., Ref. & Imp. Mtg. 3¾s Guar.	1960	99,000.00	103,000	3,750.00
50,000	West Shore R. R. Co., 1st Mtg. 4s Guar.	2361	39,070.00	32,500	2,000.00
	Income from bonds called, sold, or redeemed	.....	.....	.....	157,776.09
$950,000	Total Railroad	.....	$949,594.61	$1,062,500	$197,651.09

* After deduction for amortization of premiums on bonds purchased subsequent to January 1, 1940.

SCHEDULE OF SECURITIES OWNED OCTOBER 31, 1946—*Continued*

Aggregate par or nominal value	Description	Maturity	Cost, amortized cost, or value at date acquired	Market value	Interest income for year
	INDUSTRIAL AND MISCELLANEOUS BONDS				
$198,000	Eastern Gas and Fuel Associates, 1st Mtg. & Coll. Tr. 3½s	1965	$202,106.49*	$209,880	$6,930.00
300,000	Goodrich (B. F.) Company, 1st Mtg. 2¾s	1965	301,421.06*	306,000	8,250.00
75,000	Greyhound Corporation, S. F. Deb. 3s	1959	75,803.58*	77,250	2,250.00
147,000	Phillips Petroleum Co., S. F. Deb. 2¾s	1964	148,282.21*	151,410	4,042.50
57,000	Railway Express Agency, Serial Notes 2¼s–2½s	1946–48	57,000.00	57,000	1,336.25
300,000	Seagram (Joseph E.) & Sons, Inc., Deb. 2½s	1966	298,500.00	291,000	−999.99
400,000	Shell Union Oil Corp., Deb. 2½s	1971	405,890.91*	392,000	4,388.81
250,000	Socony-Vacuum Oil Co., Deb. 2½s	1976	249,185.00	245,000	−277.79
250,000	Union Oil Company of California, Deb. 2¾s	1970	260,200.00	252,500	−951.06
100,000	Westinghouse Electric Corporation, Deb. 2⅝s	1971	100,500.00	101,000	−72.93
	Income from bonds called, sold, or redeemed	...	....	.	33,789.37
$2,077,000	Total Industrial and Miscellaneous		$2,098,889.25	$2,083,040	$58,685.16
	MORTGAGES				
	Income from mortgages sold or liquidated		....	.... ..	$2,567.18
	BONDS AND MORTGAGES—Funds Invested	..	$21,950,326.46	$22,539,588	$758,680.27

* After deduction for amortization of premiums on bonds purchased subsequent to January 1, 1940.

Schedule of Securities Owned October 31, 1946—*Continued*

Number of shares	Description	Cost, amortized cost, or value at date acquired	Market value	Dividends for year
	Preferred Stocks			
2,504	American Cyanamid Co., 5% Cum. Pref.	$28,059.62	$27,544	$1,252.00
1,000	Anchor Hocking Glass Corp., $4.00 Cum. Pref.	112,750.00	112,000	4,000.00
1,500	Appalachian Electric Power Co., 4½% Cum. Pref.	159,000.00	169,500	6,750.00
2,000	Armstrong Cork Co., $3.75 Cum. Pref.	205,500.00	208,000	7,500.00
1,500	Bethlehem Steel Corp., 7% Cum. Pref.	183,637.50	228,000	10,500.00
1,477	Bristol Myers Co., 3¾% Cum. Pref.	156,300.45	158,039	5,538.75
2,000	Buffalo, Niagara Electric Corp., 3.60% Cum. Pref.	207,990 00	206,000	5,400.00
500	Case (J. I.) Co., 7% Cum. Pref.	62,225.00	77,000	3.447.64
600	Cleveland Electric Illuminating Co., $4.50 Cum. Pref.	68,112.25	66,600	2,700.00
1,000	Columbus and Southern Ohio Electric Co., 4¼% Cum. Pref.	115,350.00	113,000	3,180.00
1,125	Continental Can Co., Inc., $3.75 Cum. Pref.	115,312.50	119,250	4,218.76
145	Corn Products Refining Co., 7% Cum. Pref.	27,183.25	27,840	1,015.00
900	Deere & Company, 7% Cum. Pref.	25,931.25	30,600	1,260.00
1,125	duPont (E. I.) de Nemours & Co., $4.50 Cum. Pref.	116,125.00	141,750	5,062 52
1,500	Electric Power and Light Corp., $7.00 Cum. 1st Pref.	253,700 00	219,000	7,875.00
1,000	El Paso Natural Gas Co., 4.10% Cum. Pref.	111,442.21	111,000	1,025.00
1,500	General Motors Corp., $5.00 Cum. Pref.	187,937.50	190,500	7,500.00
1,000	General Shoe Corporation, $3.50 Cum. Pref.	102,250 00	102,000	1,325.00
1,300	Goodrich (B. F.) Co., $5.00 Cum. Pref.	129,867.50	133,900	6,500.00
700	Goodyear Tire & Rubber Co., $5.00 Cum. Pref.	73,195.00	74,900	3,500.00
1,000	Grant (W. T.) Co., 3¾% Cum. Pref.	100,447.91	105,000	3,750.00
2,000	May Department Stores Co., $3.75 Cum. Pref.	212,800.41	212,000	6,646.88
1,500	McKesson & Robbins, Inc., $4.00 Cum. Pref.	144,000 00	160,500	6,000.00
525	Monsanto Chemical Co., $3.25 Cum. Pref. "A"	53,287 50	63,525	152.25
1,000	New York State Electric & Gas Corp., 5.10% Cum. Pref.	103,250 00	106,000	5,100.00
1,000	Northern States Power Co., $3.60 Cum. Pref.	103,200 00	103,000	900.00
695	Ohio Power Co., 4½% Cum. Pref.	76,552.00	80,620	3,127.52
1,500	Pacific Telephone and Telegraph Co., 6% Cum. Pref.	235,220 75	247,500	9,000.00
1,000	Panhandle Eastern Pipe Line Co., 4% Cum. Pref.	104,166.68	104,000	4,000.00
1,600	Philip Morris & Co., Ltd., Inc., 4% Cum. Pref.	171,737.50	172,800	6,400.00
1,000	Pillsbury Mills, Inc., $4.00 Cum. Pref.	107,722.00	104,000	4,000.00
1,000	Public Service Co. of Oklahoma, 4% Cum. Pref.	105,286.00	107,000	3,900.00
2,000	Reynolds (R. J.) Tobacco Co., 3.60% Pref.	199,683.75	208,000	7,200.00
1,000	Servel, Inc., $4.50 Cum. Pref.	112,625.00	108,000	4,500.00
1,134	Sherwin-Williams Co., 4% Cum. Pref.	124,985.95	127,008	4,536.00
1,400	Standard Oil Co. of Ohio, 3¾% Cum. Pref. "A".	150,743.69	147,000	3,131.25
250	United States Gypsum Co., 7% Cum. Pref.	45,187.50	47,750	1,750.00
1,500	U. S. Rubber Co., 8% Non Cum. 1st Pref	184,337 50	235,500	12,000.00
3,100	U. S. Steel Corp., 7% Cum. Pref.	443,407.57	455,700	21,700.00
	Income from stocks called, exchanged, or sold			13,041.33
48,580	Total Preferred Stocks	$5,220,510 74	$5,411,326	$210,384.90

Schedule of Securities Owned October 31, 1946—*Continued*

Number of shares	Description	Cost, amortized cost, or value at date acquired	Market value	Dividends for year
	Common Stocks			
200	Air Reduction Company	$11,989 46	$7,000	$350.00
2,000	American Can Company	178,020 88	164,000	4,800.00
4,200	American Cyanamid Co.	162,183.16	197,400	2.625.00
2,000	American Gas and Electric Company	88,419 88	80,000	1,000.00
2,700	American Telephone & Telegraph Co	399,025 39	448,200	24,300.00
3,000	Armstrong Cork Company	144,434.27	138,000	1,200.00
3,600	Boston Edison Company	163,790 21	180,000	4,560.00
2,800	C. I. T. Financial Corporation	141,857.73	109,200	5,000.00
700	Caterpillar Tractor Co.	47,333.73	42,700	2,100 00
2,300	Chase National Bank of N. Y.	81,819.35	85,100	2.040.00
4,000	Chrysler Corporation	364,082 32	332,000	8,700.00
2,500	Cleveland Electric Illuminating Company	110,898 36	102,500	2,750.00
900	Coca-Cola Company	121,233.75	122,400	2,800.00
1,300	Colgate-Palmolive-Peet Company	51,736 15	61,100	1,650.00
2,000	Commercial National Bank and Trust Co. of N. Y.	86,522.22	82,000	3,200 00
5,556	Commonwealth Edison Company	172,956.09	177,792	4,484 20
2,000	Consolidated Edison Company of N. Y.	67,530.37	56,000	800.00
1,000	Consolidated Gas, Electric Light and Power Company of Baltimore	90,349 75	75,000	900.00
4,300	Continental Can Co.	172,761.85	167,700	2,400.00
1,100	Continental Illinois National Bank & Trust Co. of Chicago	96,510.00	102,300	3,600.00
2,808	Continental Insurance Co.	105,654.17	129,168	5,616.00
6,000	Continental Oil Co. of Delaware	162,943 08	210,000	9,600.00
5,100	Delaware Power & Light Company	105,714 47	102,000	3,387.50
400	Dow Chemical Co.	53,363 54	64,000	975 00
2,400	duPont (E. I.) de Nemours & Co.	382,940 61	412,800	12,500 00
2,200	Eastman Kodak Co.	365,025 00	457,600	14,000 00
17	First National Bank of N Y.	25,982 80	27,540	1,360 00
1,593 75	Food Machinery Corporation	90,941.02	124,311	2,008.10
9,300	General Electric Co.	366,839 34	344,100	11,680.00
6,500	General Foods Corporation	274,377 81	299,000	7,740.00
8,000	General Motors Corporation	423,115 49	408,000	15,000.00
500	Goodrich (B. F.) Co.	27,775 58	33,000	1,175 00
600	Goodyear Tire & Rubber Co	31,329 19	33,600	750.00
10,000	Grant (W. T.) Co.	181,260 49	300,000	8,495 00
360	Guaranty Trust Co. of N. Y.	98,003 91	117,360	4,320.00
8,500	Gulf Oil Corp.	366,532 37	535,500	17,000.00
1,600	Hartford Fire Insurance Co.	138,851 06	156,800	3,750.00
8,000	Humble Oil & Refining Co.	239,092 33	472,000	12,000.00
2,775	Insurance Company of North America	188,687 06	249,750	8,325.00
1,400	International Business Machines Corp.	146,992 04	292,600	8,049.00
1,000	International Nickel Company of Canada, Ltd.	30,588 46	29,000	1,360.00

(*Continued on following page*)

SCHEDULE OF SECURITIES OWNED OCTOBER 31, 1946—*Continued*

Number of shares	Description	Cost, amortized cost, or value at date acquired	Market value	Dividends for year
	COMMON STOCKS—*Continued*			
900	Johns-Manville Corp.	$97,904.61	$109,800	$1,750.00
1,500	Kennecott Copper Corporation	57,944.06	67,500	2,500.00
3,300	Kresge (S. S.) Company	75,867.59	132,000	5,280.00
2,100	Liggett & Myers Tobacco Co., "B"	189,977.30	195,300	6,650.00
800	Liquid Carbonic Corporation	21,032.21	20,800	800.00
320	Mellon National Bank and Trust Company	67,193.07	93,440	.....
1,600	Merck & Co., Inc.	65,303.57	92,800	1,600.00
2,700	Minneapolis-Honeywell Regulator Co.	123,415.63	145,800	1,820.00
6,600	Monsanto Chemical Co.	211,865.19	323,400	1,500.00
5,900	Montgomery Ward & Co.	315,530.92	395,300	9,500.00
5,100	National Cash Register Co.	153,073.19	163,200	5,475.00
1,500	National City Bank of New York	60,412 50	61,500	1,600.00
1,260	National Fire Insurance Co. of Hartford	72,819.72	65,520	2,520.00
225	National Union Fire Insurance Co.	38,900.90	31,500	1,125.00
10,800	Newberry (J. J.) Co.	143,047 69	291,600	9,180.00
2,300	New Jersey Zinc Co.	147,347 02	142,600	6,900.00
3,300	Owens-Illinois Glass Co.	227,449.50	244,200	5,850.00
2,500	Pacific Gas & Electric Company	114,823.09	102,500	1,250.00
8,000	Penney (J. C.) Co.	250,062.28	376,000	15,170.00
1,000	Peoples Gas Light and Coke Company	106,350.00	93,000	1,000.00
1,700	Pepsi-Cola Company	40,321.03	44,200	584.50
500	Pfizer (Chas.) & Co., Inc.	29,711.43	30,500	.....
3,500	Philadelphia Electric Company	100,048.39	91,000	1,050.00
6,200	Phillips Petroleum Co.	310,446.88	353,400	10,400.00
7,200	Pittsburgh Plate Glass Co.	221,069.45	266,400	3,080.00
2,100	Procter & Gamble Co.	117,585.87	119,700	4,200.00
1,500	Scott Paper Co.	61,907.05	64,500	2,700.00
16,400	Sears, Roebuck & Co.	374,427.57	639,600	17,250.00
1,100	Sharp & Dohme, Inc.	15,513.34	30,800	825.00
2,300	Sherwin-Williams Co.	259,541.88	308,200	6,300.00
2,000	Southern California Edison Company, Ltd.	79,234.53	68,000	750.01
5,500	Squibb (E. R.) & Sons	136,373.89	242,000	3,225.00
2,800	Standard Brands Incorporated	106,459.15	100,800	1,620.00
7,800	Standard Oil Co. of Indiana	253,821.68	312,000	9,425.00
5,500	Standard Oil Co. of New Jersey	311,318.84	368,500	10,725.00
1,600	Texas Company	67,355.82	96,000	4,000.00
2,700	Timken Roller Bearing Co.	130,378.34	110,700	5,062.50
3,800	Union Carbide & Carbon Corp.	333,875.55	349,600	7,950.00
9,400	United Fruit Company	266,728.02	432,400	13,300.00
2,600	United States Gypsum Co.	234,100.84	270,400	4,200.00
10,500	Westinghouse Electric Corp.	276,080.07	262,500	9,000.00
3,600	Woolworth (F. W.) Co.	155,423.59	180,000	3,780.00
	Income from stocks exchanged or sold	.....	.....	31,732.50
289,214.75	Total Common Stocks	$12,981,507.99	$15,417,481	$460,979.31
337,794.75	COMMON AND PREFERRED STOCKS—Funds Invested	$18,202,018.73	$20,828,807	$671,364.21
	AGGREGATE INVESTMENTS (BONDS AND STOCKS)	$40,152,345.19	$43,368,395	$1,430,044.48*

* Represents total interest and dividend income before deduction of amortization of bond premiums.

NOTE: Net gain from sales and redemptions of securities for the year ended October 31, 1946 aggregated $1,053,096.80, and that amount has been credited to the Capital Reserve Fund shown in the attached balance sheet.

REPORT OF THE PRESIDENT

OF THE

CARNEGIE INSTITUTION OF WASHINGTON

FOR THE YEAR ENDING OCTOBER 31, 1946

REPORT OF THE PRESIDENT

OF THE

CARNEGIE INSTITUTION OF WASHINGTON

As this report to the Trustees of the Carnegie Institution of Washington is presented, in accordance with the By-Laws, many of the Institution's major concerns are subject to new and profound influences. The war has placed science in an utterly new position. Just what this position is, and how it may be expected to affect the affairs of the Institution, are matters well worth analysis now that we are turning to programs of peace.

The reason that there is an altered position for science is very clear. It is now recognized all over the world that the application of science is central in national security. During the second world war, the nature of warfare underwent a complete transformation. This was of much greater scope than could have been indicated by the actual hostilities from 1939 to 1945, for changes in the methods of making war do not produce their full effect at once. It is not sure that great armies and great fleets are obsolete, but it is sure that if there were another great war it would be vastly different in its nature from anything that has preceded. The revolution is greater than that brought about by the advent of gunpowder, or that occasioned by the use of shells and the consequent entry of the armored ship. It is, in fact, greater than the mere influence of a technique, for it involves rather a methodology for applying techniques. The results, then, in the long run can be as far reaching as those which came to pass when men learned that inventions can be made by deliberate planned effort, or when tools were caused to make more tools and thus to multiply themselves. Full comprehension of the fundamental change in all of mankind's concerns which is foretold in this scientific revolution in warfare cannot be had for some time; the implications are too numerous, too involved, too subtle. Such comprehension will come, nevertheless; it is inevitable in view of the way in which the past war was conducted by all participants and the lessons that were thus recorded for all to read.

This present sweeping transformation of mankind's affairs had its beginning when the first simian developed curiosity, when he came to manipulate the objects in nature about him not for immediate animal ends, but simply because he had a new urge. The appearance of that urge marked the advent of the inchoate human intelligence as a wholly new factor in a hitherto drab evolution. It thus began the great experiment in which we participate. It is an experiment which surely will go on to full and richer scope, for man's urge to learn and to know more about his environment and his fellows will not end now. Yet by its intermediate results our days are now perplexed.

The world which faces this multiplex problem and opportunity is still in a highly nationalistic phase of organization. It was this fact that Churchill undoubtedly had in mind when he declared the world not yet ready for such an advance as the development of atomic energy. But the world

has never been ready in that sense: it was not ready for the advent of the use of fire, or of metals, or of chemistry, or of mass communication. This time, however, there is a difference, for there is a general recognition that the advance, through its acceleration of the evolution of weapons, bids fair to proceed so far as to render some form of world unity inevitable. This generally held conviction, however, leads to far different concepts with different groups and with different individuals. To many, taking the world as a whole, it points inevitably to a Roman peace, one world under some sort of domination, held together by the very power of the new instrumentalities. But there is a large and salutary endeavor for a better result—effort for a voluntary joining of states under some scheme of guarantees that will protect minorities. This is not idle dreaming; the formation of the United States by the voluntary joining of the Colonies, and other unions as well, had their origin in similar efforts. We need not be dismayed even by the raucous accusations and turmoil of the present day, for the colonies in North America before they became states, and even after, indulged in similar recriminations as they worked toward union. Still, anything approaching a unitary world has never yet been achieved on the basis of voluntary association, and the accomplishment will take time. The principal question is whether there will be time enough—whether, in short, there must be another demonstration of the power of applied science to destroy before mankind as a whole recognizes that a new approach toward international functioning is demanded. This is a serious question. But it is doubtful whether civilization will commit suicide knowing it is doing so, and because of science the race between the power of weapons and the power of understanding is not altogether one-sided.

For the application of science has done more than produce a power of destruction which has made a world organization essential. It has in fact also provided means of primary importance to the development of such organization, in the form of universal communication, the printed word, transmitted speech, swift transport. Real unity can be achieved only through general mass enlightenment throughout the world, and hundreds of millions of people cannot know one another except as new instrumentalities free them from the narrow limits of mere personal contact. It should also be remembered that the application of science can alleviate as well as destroy. In fact, the progress in medicine under the forced draft of war in the past conflict was such that the number of lives saved goes far toward balancing battle casualties. Still more important, perhaps, great masses of people now have the definite promise before them of leading healthy lives, especially in the tropics, and a healthy outlook on life is necessary for great movements of collaboration.

All this furnishes the background for the position of science in our own national scene, and is pertinent as we examine into the future of the Institution. There is no question that scientific effort in this country will now expand to a far greater proportion of the total volume of effort than was the case before the war. Nor is there question that as it does so it will receive public attention and public support. On the expanding scale which the national interest requires and dictates, federal support of scientific effort now becomes essential and also inevitable. The form that it may take is of great importance. Many dangers may be discerned here, and it will be well to review some of them.

First, there is the danger that there will be overemphasis on the applied phase of science, for the public is alert to the tangible benefits to be had from it, but hardly realizes the fact that they are all dependent upon long-term advance in fundamental science. Fortunately, in the immediate postwar period at least, this danger has been averted. Federal support to university research is already flowing in large measure, and it is now directed heavily toward support of basic science. But this may be a passing phase, and the danger certainly remains, for as a people we are strongly philotechnical, we have always excelled in the applied, we have not turned with the same success to more philosophical matters. In many branches of science we have as a nation hence lagged behind Europe.

There is also a danger that control of funds may occasion injurious dictation to science by laymen. The fact that this is a somewhat subtle matter renders the danger much greater. In applying science it is often correct that a group of laymen should set the general objectives—in industrial research, for example, where men of diverse backgrounds and interest need to meet with the scientists and engineers in order to create a program that is sound from the standpoint of the industry. The governing boards of universities rightly participate as the scientific research programs of their institutions are formulated, not merely because they must assure that plans and means shall be commensurate, but also, and more important, because they must counsel in the defining of broad objectives which reach beyond the direct interests of the scientists into the greater question of the ultimate best interests of the country. In both cases, however, once the general objectives are defined, wise management leaves the methods of approach entirely to the scientists. The danger is that this lay participation will go beyond its appropriate function, enter into the methods themselves, and seek to influence the choice of the particular paths to be followed. If a scientist is really competent in his field, he knows better than anyone else how, in the exceedingly complex situation surrounding the frontier of knowledge, to single out an approach which may lead toward great attainment. Interference with him by any individual, board, or committee as he thus determines his way annoys him greatly, and should. The finding of the path is one of the finer parts of his art; in fact his rise to eminence depends very decidedly upon the wisdom with which he can thus choose.

To illustrate, there is today in this country a great urge to clear up once and for all at least the worst aspects of the great curse of cancer. Moreover, because of recent advances, new approaches of promise exist. Certainly funds poured into this field at the present time are well invested. Yet how does one proceed from here? One method favorably known to Americans because of the great advances which it has produced in applied science is to assemble a group of highly intelligent citizens, to build great laboratories and install therein competent scientists, and to create patterns of effort paralleling those that have been successful in large industrial laboratories, with the single aim of finding a cure. But there is an alternative method, recommended by its admirable results in fundamental research. This is to select scientific men of great power—men who are thus regarded by their colleagues —and see to it that they get every bit of support which they can utilize effectively, in their own undertakings, and in accordance with their own plans. Such an effort should cover every contributory field, and hence the entire science of man's physical

and chemical constitution and growth. It might be that the first method would find a solution—such things do happen. The question is essentially one of timing. If investigation of cancer has come to the stage of applied research, then the organized approach is entirely sound. If that investigation is still in the stage demanding fundamental research—and the evidence emphatically indicates that it is—then the second method is the one to follow. Through it, by and large, have come the great accomplishments in fundamental science, and it is sure to bring results in the long run, in many fields of application at once, and over a broad range. The characteristic and productive urge of Americans to move swiftly into applied research for immediate and practical results could easily lead to the ignoring of this vital fact.

The question of just where governing boards should stop in their proper control of funds as they deal with scientists of eminence has not, however, been a serious problem, for in this country sound understanding on the matter has rather generally been established. It becomes important at the present time because new governmental boards of one sort or another will be controlling federal funds for scientific research, and it is essential that the productive pattern which has been developed in the past should not now be departed from simply because pressure exists and because the funds are large.

This raises the question, of course, whether the flow of funds into university research will lead to federal domination of universities in one way or another. It need not do so. The history of state universities in this country shows how public funds can be devoted in an effective way to education and research, for in spite of exceptions the general pattern of our state universities today is excellent. Nevertheless, federal and state support are markedly different matters, and alert understanding will be needed as the system of federal support develops.

A comparable danger, that there will be overemphasis on the military aspects of science, is to the fore at the present time since federal funds are flowing from the military services into basic research. This system, however, is undoubtedly a temporary one, and the support is being rendered in a highly intelligent manner, without undue control by officers of the military services and with strong emphasis on fundamental research. After the experience of the past six years, a tendency in this country toward overemphasis on applications to military matters would perhaps be natural, but this has been to the present avoided so far as fundamental research is concerned. There is the converse danger, of course, that in a period of reaction such as we experienced between the two world wars we might neglect the national security to our peril. The fraction of the country's effort in applied research and development which need be devoted directly to national security still remains to be determined; the proportion naturally depends upon the progress of world affairs. The maintaining of a just balance will not be easy.

Finally, there is a danger that the fierce present light thrown by extraordinary applications may blind men to the lasting cultural and philosophical significance of science and that therefore the moral and intellectual endorsement of this phase of the search for truth may diminish. Since indeed fundamental research probably will always be assured of financial support simply because it is the source of knowledge that can later be applied in different ways, this hazard is not one of material impoverishment, but rather one of intellectual if not spiritual disparagement. In this

country in particular, the popularization of science has fed us with the spectacular until the public must be near satiation, and has already to a degree served to obscure from the less thoughtful the deeper significance of the exploration of the unknown—its relevance in all of man's most earnest ponderings upon himself, his fellows, his environment. Without doubt this serious interest in science because of the basis for broad philosophical reasoning furnished by its advances persists. It persists also because of mankind's innate curiosity, and a regard for the new and unique in thought. Even so, in the days of the atomic bomb, one may fairly question whether the spirit that led to the exploration of the nucleus of the atom as a sheer expression of man's response to the challenge of the unknown will continue assured of true assessment of the philosophical values with which it is imbued.

The position of science in the world thus is changed. The position of the Carnegie Institution of Washington is bound to alter as a result. Definitely before us is the question of what new responsibilities or new opportunities may now appear.

One issue is immediately raised. To what extent should the Institution participate in the new forms of support that are either present or just about to appear? The record of the Institution during the war was more than the fine record of the accomplishments of its laboratories. By reason of its national nature and its full independence it exerted an impelling influence along with many another institution in the great cooperative venture in which hundreds—thousands—of scientists spread over a continent and throughout many institutions collaborated in a new pattern and produced vital results. As the new pattern evolves and our scientific effort appears in a novel framework, it will similarly be to the advantage of the country that there be a national institution of complete independence.

Another issue is immediately before us. As government enters into the scientific situation in new ways, there will inevitably be greater participation of scientists in governmental matters. This participation will be entirely apart from individual activity by scientists as citizens in political affairs, at which they are usually not highly adept. It will be concerned, rather, with the problem of manning the many boards and committees which are essential, and the furnishing of background and special experience to those who make the laws and administer them. In all this there will undoubtedly be a duty and an opportunity for scientific and educational institutions throughout the country; the Carnegie Institution of Washington in this regard is again in a somewhat exceptional position, and again I believe that to a reasonable extent it can grasp such opportunities with real benefit to itself and to the country.

The opportunity before the Institution in the years that lie ahead is vast, and the relative size of the Institution is now small. When it was founded, its introduction of half a million dollars a year into basic research constituted a considerable fraction of the national effort, and the effect was therefore bound to be great. Today, the expenditures of the Institution compose only one per cent of the funds devoted to fundamental research and only one-tenth of one per cent of total funds for research and development.

The Institution's history during the past four decades demonstrates convincingly, however, that the importance and excellence of scientific effort are determined by many things, not by funds alone. It was because of such determinants as intensity of application, clarity of definition, breadth

of objective, that the Institution had attained before the recent war the stature which enabled it to contribute powerfully indeed in the national effort, and to serve as a center in the most extensive cooperative research undertaking in history. These determinants have taken on more, not less, force. Hence, as long as it does not become so cramped for funds as to lose its flexibility, the Institution will continue to be a pervasive and beneficent influence in the scientific life of the nation. The avenues of that influence are not far to seek: Preserving its excellence and uniqueness to the full, utilizing its national spread and its complete independence, the Institution will make itself felt in the future as it has in the past. Forty and more years ago, the Institution was practically alone in its field; today, it has many and able compeers to emulate and by whom to be stimulated. Though it does not and should not now seek to cover the whole of science, it will lead the way in certain activities, and do so the more vigorously because its earlier concern with other endeavors has been relinquished to capable hands.

The most important thing for the Institution to do is to lend its influence and emphasis to those needs that might now be overlooked. It should and will firmly support fundamental science if there should be a tendency toward the over-applied. In the effective and logical pattern of relations in its organization, between its governing bodies and its scientific staff, it has developed and now exemplifies a way of operation that is sound and fruitful. It should and will lend its influence when the great question develops of the balance between applied science for national security and applied science for other great objectives. It can aid in a hundred ways as government proceeds into new relations with the scientific effort. It will most decidedly emphasize that the pursuit of science for its cultural value remains a thing worthy of men's best effort.

Financial Affairs

During the past year the Executive Committee and the Finance Committee have considered the effect of declining income on the operations of the Institution and have discussed the possible use of reserves in planning for the future. Although our endowment has been materially increased, low interest rates and the redemption of prewar bonds result in an income which leaves little or no leeway to meet the unusual costs of living and operation in a postwar economy. We have been able to increase reserves destined for use in putting our physical house in order again. The necessity of increasing salaries, however, and the requirements for going forward with new programs pose a real financial problem.

There are four possible ways of meeting this situation: (1) revision of investment procedures to yield a higher return; (2) temporary use of reserves, with which we are well fortified; (3) curtailment of research activities; and (4) securing of new money. Fortunately we do not need to select one of these irrevocably at the moment; economy, restraint, and the judicious use of reserves for nonrecurring expenses will see us through the next year. But the whole problem will certainly have to be met before long, unless the trend of income on endowment reverses.

Careful study of ways and means with due regard for continuing obligations has been made in preparing recommendations for a budget for the coming year. These recommendations provide for initial steps

to bring our salary and wage scale to a level fully comparable with those of other leading educational and research agencies. Items for additional expenses have also been included without which it would be impossible to take advantage of the present opportunity to revitalize activities of the Institution on the basis of the constructive and forward-looking research programs under consideration. It has not been possible to provide for employment of new personnel to the extent which is desirable. About all of the reasonable economies in operation that can be found have already been put into effect. We have terminated auxiliary effort so that we are now concerned only with the affairs of our main departments. Our aid to others working in parallel fields has almost ceased. The programs which have been formulated by the departments will require moderate use of reserves for nonrecurring items, but not to such an extent at present as to jeopardize future income. It is to be hoped that a few years of this kind of financing may prove sufficient to enable the Institution to carry its full load thereafter from income. It is also to be hoped, of course, that we can recover the ability to extend aid to others, and that flexibility in pioneering in new fields which forms a great part of the strength of the Institution.

Retirements and Changes

After the retirement of Dr. Carpenter as Director of the Nutrition Laboratory, reported a year ago, arrangements were completed for transfer of ownership of real estate and buildings of this Laboratory to the Children's Hospital in Boston by sale at the assessed valuation of the property. Equipment of the Laboratory at a total original cost valuation of approximately $25,000 has been distributed among various Institution activities, and other material has been donated to many scientific and educational organizations. Thus has been brought to a close another pioneering effort of the Institution in a field now ably supported by other agencies.

War activities at the Department of Terrestrial Magnetism being practically terminated, the service of Dr. John A. Fleming, first as Assistant Director and then as Director, for twenty-five years ceased with his retirement on July 1, 1946. Dr. Fleming has a distinguished record in leading and developing the productive research program of this Department and in carrying through in an exceedingly effective manner the extensive war service rendered by its entire staff. He is also a distinguished leader in international scientific affairs, particularly in the field of geophysics, and has recently been chosen as the President of the International Council of Scientific Unions. The Institution has interests which are closely concerned with governmental and international organizations, and Dr. Fleming has agreed to serve as an official adviser in such matters, particularly in arrangements with other countries for the transfer of the observing programs which have provided data for use by our Department of Terrestrial Magnetism.

Dr. Merle A. Tuve, Chief Physicist of the Department of Terrestrial Magnetism, has succeeded Dr. Fleming as Director of this Department. Elected a member of the National Academy of Sciences in 1946, along with Dr. Milislav Demerec, Director of the Department of Genetics, and Dr. Charles S. Piggot, staff member of the Geophysical Laboratory, Dr. Tuve was awarded the Medal for Merit and received the Naval Ordnance Development Award for developments, notably the proximity fuse, which proved a determining factor

in defensive anti-aircraft action by the United States Navy and resulted in material increase in the efficiency of offensive action against enemy air power.

Retiring on January 1, 1946, after more than forty years' distinguished service at Mount Wilson Observatory, twenty-three as its Director, Dr. Walter S. Adams has continued connection with the Observatory as Research Associate. His counsel hence has been available in the arrangements preliminary to the inauguration of the plan for joint operation of the Mount Wilson Observatory and the Observatory on Palomar Mountain announced upon the appointment of Dr. Ira S. Bowen as Director of the Mount Wilson Observatory, which was reported in Year Book No. 44. The trustees and officers of the California Institute of Technology and the Carnegie Institution of Washington have approved plans for the unitary operation of the scientific program of the observatories by studies on the campus of the Institute providing graduate training given under the auspices of the Institute by an astrophysics staff consisting of members of both the Institution and the Institute, and the formation of a committee to formulate a broad and long-term program of research for the combined observatories. Of this committee Dr. E. P. Hubble, of Mount Wilson Observatory, is chairman. Optical and mechanical work on the 200-inch telescope on Palomar Mountain has been resumed after wartime abeyance, and it is expected that the instrument will be in operation in the summer of 1947.

Postwar Programs

War researches of the Institution caused interruption and postponement of many normal research programs. The departments most seriously affected were the Mount Wilson Observatory, the Geophysical Laboratory, the Department of Terrestrial Magnetism, and the Department of Genetics. During the past year, with return of staff members and with occasion to study prospects for the future, there has been opportunity to lay sound basis for the restoration of peacetime activities.

Mention has been made of the committee which under the chairmanship of Dr. Hubble is engaged upon studies for the research program of the Mount Wilson and Palomar Mountain Observatories. In the Department of Terrestrial Magnetism, the Department of Genetics, and the Geophysical Laboratory, series of staff conferences, individual studies, and group analyses have resulted in the formulation of long-term programs of future research undertakings. In the development of these, critical review by investigators and scholars in other research centers has been invited, and the most searching consolidated judgment of the departmental staffs has been exercised. Submitted for consideration to the appropriate standing committees of the Trustees and to the Executive Committee, these programs constitute clear charts of the direction which investigative efforts may take for some time to come. The influence of the war on the conditions under which such work must be developed has been viewed realistically, and the proper evaluation of contributions which may result under such conditions has been emphasized. The Directors of the Departments concerned have taken leadership in the discussion, analysis, and formulation of these programs with staff members and have profited by a free expression of views based on individual vision and aspiration. At the Division of Plant Biology, a series of conferences on photosynthesis, to which

different groups of scientists from other institutions were invited and each of which was followed by full discussion within the Division, have contributed to the formation of definite conclusions for strengthening the Division's program in this highly important field. A five-day staff conference of the Division of Historical Research at Cambridge in September is basis for the formulation of recommendations for future work in that field. In the Department of Embryology, full resumption of the fundamental program set forth in Year Book No. 40 is being achieved as the hampering effects of the war terminate.

The Executive Committee of the Institution has given consideration to appropriate steps for a publication program designed primarily to aid in increasing the comprehension of scientific subjects by the intelligent layman.

Questions of the plan of staff organization best designed to assure clearer definition and understanding of tenure and similar matters have been discussed by the Executive Committee. It is important that the Institution, without relinquishing its valued informality, assure its position among its fellows by clear procedure in salaries, advancement, and tenure, and by suitable provisions for the recruitment of able younger men. Time will be required to inaugurate a plan covering such questions, to be effective with new appointments and available to the present staff; there is general recognition of the need, and steps to meet it will be taken as promptly as possible.

Research Activities

The full range of the Institution's researches during the past year is surveyed in the reports of the Directors of the several Departments. It is a broad range, marked by many significant advances. I shall here therefore attempt no more than brief mention of a few.

The great sunspot group first seen on January 29, 1946, the largest ever photographed, was recorded at Mount Wilson in numerous excellent direct photographs; in addition, it gave notable opportunity for study of the spectral characteristics of solar flares. During the year, the late Dr. van Maanen, completing measurement of the parallaxes of 28 stars in 25 fields, brought to conclusion a program of major proportions at the Observatory during the past thirty years.

At the Kensington Ionospheric Laboratory of the Department of Terrestrial Magnetism, development of a new technique for recording phenomena in the upper layers of the earth's atmosphere led to the discovery of rapidly moving clouds of ionized matter which rush into the ionosphere during magnetic storms. Traveling at a speed of about one mile per second, the clouds come in from long to short range and out again at brief intervals. They are of fundamental significance in their influence on radio transmission. The clouds are regarded as closely related to the corpuscular emissions from the sun which give rise to magnetic and ionospheric storms.

In the Division of Plant Biology the antibacterial properties of unsaturated fatty acids, study of which had its beginning in the isolation of antibacterial material from the green alga *Chlorella,* has been carried farther. Though tests with animals did not yield encouraging results, *in vitro* tests have been satisfactory. The basic biochemistry of the substances has been determined, so that a definite contribution has been made to knowledge of this general group of antibiotic substances. Further re-

sults are largely dependent on bacteriological study. A full report on the subject is in preparation.

Cooperation with the Department of Terrestrial Magnetism, whence necessary products of the cyclotron are made available, has been to the fore during the year in a portion of the research of the Department of Embryology—the subject of placental transmission, which includes as one project the transmission of phosphorus compounds from the mother to the embryo. In the study of tumors in rats, experiments earlier reported have been expanded in the search for understanding of the process of immunity from growth of grafted tumors induced by an alcohol-soluble fraction from an extract of rat sarcomata. The experiments appear to be the first in which injection of such a substance destroyed tumors in rats of its own inbred strain and was followed by the establishment of immunity against the growth of tumors in the majority of the rats treated.

Study of the genetic aspects of bacterial resistance has been pressed at the Department of Genetics, where among other findings it has been shown that resistance to streptomycin originates through a process of mutation, which, unlike the several-step process leading to resistance to penicillin, may develop in a single step. This property is of course undesirable from the clinical standpoint. In a related study, it has been concluded that the probable site of the mutational change is within the bacterium and that the change is a complex one requiring absorption of radiant energy by several molecules as a primary step.

Reorientation and review necessitated by the suspension of many activities because of war work have proceeded during the year in the Division of Historical Research, and certain field programs have been fully resumed. The reconnaissance survey of ruins in the Guatemalan highlands, initiated in 1945, has been carried forward. Incident to it was an unforeseen discovery of much interest: a grave at a depth of thirty feet which was indicated by a funnel-shaped depression in the frontal platform of one of the principal mounds at Nebaj. This yielded more than forty specimens of pottery from a little-known period, in addition to one of the most beautiful collections of jade ornaments yet discovered, numbering about 250 pieces.

Louise Whitfield Carnegie

In the death, on June 24, 1946, of Mrs. Carnegie, the Institution suffered not only the loss of its direct link with the years at the turn of the century when its founder's philanthropy was being formed, but, far more than that, the loss of a constant, keen, and gracious interest in its well-being and activity. Mrs. Carnegie's devotion and unselfishness as a wife were equaled only by the sympathy and support which she freely gave to the cause of peace and to the fostering of enlightenment and knowledge during the years following her husband's death.

Thomas Barbour

Thomas Barbour died on January 8, 1946, in his sixty-first year, after an extended period of ill health. He was elected a member of the Board of Trustees of the Institution in December 1934, and in recent years he served as a member of its stand-

ing committee on biological sciences. He took an enthusiastic interest in the broad aspects of research in these departments of learning, and he was recognized and acclaimed as a leader in biological field exploration.

Dr. Barbour was the most genial of men, with sympathy and understanding of a high and helpful order. He was widely known in scientific circles as a keen student and wise adviser, and his membership on the Board of Trustees was to the distinction and credit of the Institution. His presence and counsel will be sadly missed.

REPORTS OF DEPARTMENTAL ACTIVITIES AND COOPERATIVE STUDIES

ASTRONOMY

Mount Wilson Observatory

TERRESTRIAL SCIENCES

Geophysical Laboratory
Department of Terrestrial Magnetism
Special Projects

BIOLOGICAL SCIENCES

Division of Plant Biology
Department of Embryology
Department of Genetics

HISTORICAL RESEARCH

Division of Historical Research

MOUNT WILSON OBSERVATORY

Pasadena, California

IRA S. BOWEN, *Director*

The present year was marked by the retirement of Dr. Walter S. Adams as Director on January 1, 1946. Dr. Adams was one of two assistant astronomers brought to Mount Wilson by Dr. Hale when the Observatory was organized in 1904. In the early years of the Observatory, he served in succession as head of the Computing Division and of the Department of Stellar Spectroscopy. During Dr. Hale's frequent absences from the Observatory, Dr. Adams took charge as Acting Director. In 1913, he was appointed Assistant Director, and in 1923, on Dr. Hale's retirement, he was made Director.

As an active observer Dr. Adams has personally contributed a substantial fraction of the output of the Observatory throughout its forty-two years of operation. His early solar investigations and his development of the field of spectroscopic parallaxes have been especially noteworthy. As Director, Dr. Adams has provided a sound and understanding leadership. Under his guidance the high standards set by Dr. Hale for the Observatory have been maintained, and in spite of the depression and the late war, substantial advances in equipment and personnel have been made under his direction.

It is with much satisfaction that the present staff looks forward to Dr. Adams' continued connection with the Observatory as Research Associate. His sound and experienced advice will be of great value in the extensive reorganization that lies ahead.

An event of great importance to the future of the Observatory was the announcement of the approval by the California Institute of Technology and the Carnegie Institution of Washington of an agreement for the joint operation of the Mount Wilson Observatory and the Observatory on Palomar Mountain with its 200-inch and 48-inch Schmidt telescopes.

Since the inception of the plan for building a 200-inch telescope and the grant of funds for this purpose by the General Education Board to the California Institute of Technology, the Institute and the Carnegie Institution of Washington through its Mount Wilson Observatory have cooperated closely in the design of the instrument and in plans for its future operation. The two large neighboring observatories at Mount Wilson and at Palomar Mountain with their powerful equipment and common scientific interests and problems have every reason to work together on a unified program of astronomical and astrophysical research.

With the outbreak of the war both the optical and the mechanical work on the 200-inch telescope were suspended. They have now been resumed, however, and it is estimated that the instrument will be completed within a period of about one year. In view of this situation the trustees and officers of the two institutions have approved the formulation of a definite plan of cooperative research to be undertaken as soon as the Palomar equipment is completed. The essential parts of this agreement are as follows:

The scientific program of the two observatories will be operated as a unit. All

equipment at both observatories will be available as needed for any part of this program.

To facilitate this program the two observatories will be placed under a single administrative management, having a Director who will be Chairman of an Advisory Management Committee with representatives from both organizations.

The research program of the observatories will be reinforced by studies on the campus of the California Institute, and graduate training leading to the doctorate will be given under the auspices of the California Institute by an astrophysics staff consisting of members of both the Institution and the Institute.

The financial support of the two observatories will be contributed by the two Institutions as their resources permit.

An essential feature of this plan is the formation of a committee to study and formulate a program of research for the combined observatories on a broad, long-period basis. Dr. E. P. Hubble has been appointed Chairman of this committee. The other members are Drs. R. C. Tolman and J. R. Oppenheimer of the California Institute staff, and Drs. W. Baade, P. W. Merrill, and S. B. Nicholson of the Mount Wilson Observatory staff.

The cessation of hostilities early in the year covered by this report has made it possible for the Observatory once again to turn its main effort to its normal peacetime activities. All investigations undertaken under contract with the Office of Scientific Research and Development have been completed. These contracts have been terminated except for minor details involving disposal of government property and final financial settlement. One small contract with the United States Army is still in force but will be completed in September 1946. With one exception, all members of the scientific staff on leave of absence have returned.

STAFF AND ORGANIZATION

Research Division

Solar Physics: Harold D. Babcock, Seth B. Nicholson, Joseph O. Hickox, Edison R. Hoge, Edison Pettit, Robert S. Richardson, Mary F. Coffeen, Elizabeth S. Mulders, Myrtle L. Richmond.

Stellar Motions and Distances: Ralph E. Wilson, Adriaan van Maanen, A. Louise Lowen, Myrtle L. Richmond.

Stellar Photometry: Walter Baade, Mary Joyner Seares.

Stellar Spectroscopy: Paul W. Merrill, Walter S. Adams, Horace W. Babcock, Ira S. Bowen, William H. Christie,[1] Theodore Dunham, Jr.,[2] Milton L. Humason, Alfred H. Joy, Rudolph Minkowski, Roscoe F. Sanford, Gustaf Strömberg, Olin C. Wilson,[3] Ada M. Brayton, Sylvia Burd, Cora G. Burwell, Dorothy D. Locanthi, A. Louise Lowen.

Nebular Photography, Photometry, and Spectroscopy: Edwin P. Hubble,[4] Walter Baade, Milton L. Humason, Rudolph Minkowski, Sylvia Burd, Alice S. Beach.

Physical Laboratory: Robert B. King.[3]

Editorial Division: Paul W. Merrill, editor; Elizabeth Connor, assistant editor and librarian; Alice S. Beach, Helen S. Stecki, secretaries and stenographers.

Alfred H. Joy has continued as Secretary of the Observatory throughout the year.

In addition to the retirement of Dr. Adams and the appointment of Ira S. Bowen as his successor, effective January 1, 1946, the following changes in the staff have occurred during the year:

After two years of ill health Dr. Adriaan

[1] On leave of absence until April 1, 1946.

[2] On leave of absence.

[3] On leave of absence until January 1, 1946.

[4] On leave of absence until December 1, 1945.

van Maanen died on January 26, 1946, thus bringing to a close his thirty-four years' association with the Observatory. His extensive contributions were chiefly in the field of stellar motions and parallaxes. Dr. Gustaf Strömberg resigned to give his full time to studies and writing of a general type, his resignation becoming effective January 1, 1946. Dr. Strömberg joined the staff in 1917 and has devoted his attention to statistical studies of stellar velocities and their relation to star streaming and stellar magnitudes. Dr. Horace W. Babcock joined the staff on January 1, 1946. His chief interest will be in stellar spectroscopy and in the development of instruments using electronic techniques.

Miss Mary Joyner (Mrs. Frederick H. Seares) resigned on January 1, 1946, after thirty-one years' service at the Observatory. During most of this period she was engaged in statistical studies in stellar photometry. Miss Ada M. Brayton resigned from the computing staff of the Division of Stellar Spectroscopy on July 1, 1946. She joined the staff in 1915. Mr. William H. Christie resigned on April 1, 1946. Since coming to the Observatory in 1929, Mr. Christie has been engaged in spectroscopic studies. On June 1, 1946, Miss Alice Beach was transferred from the Editorial Division to the Division of Nebular Photography, Photometry, and Spectroscopy. On the same date her position in the Editorial Division was taken by Miss Helen Stecki.

Research Associates

Walter S. Adams, Pasadena; Sir James Jeans, Dorking, England; Henry Norris Russell, Princeton University; Frederick H. Seares, Pasadena; Joel Stebbins, University of Wisconsin.

Since his appointment as Research Associate, Dr. Adams has continued his investigations of the spectra of stars observed with high dispersion with the coudé spectrograph, including particularly the behavior and structure of the interstellar lines in the spectra of 300 stars of types O and B; a detailed investigation, in collaboration with Dr. Greenstein, of the spectrum of υ Sagittarii; and further measurement of supergiant M-type stars like α Orionis, which show shell-like characteristics in their spectra.

Dr. Seares, with the collaboration of Miss Joyner, has continued his studies of the magnitudes and colors of stars.

Dr. Stebbins spent the summer of 1945 at Mount Wilson in continuation of his work on photoelectric photometry of stars and nebulae. He was rejoined for the summer of 1946 by Dr. A. E. Whitford, who had been absent for five years on war service. Dr. Stebbins substituted for Dr. Walter S. Adams, Vice-President of the International Astronomical Union, at the meeting in Copenhagen, March 7–12, 1946.

Temporary Associates

Dr. C. G. Abbot, of the Smithsonian Institution, spent several weeks at the Observatory in the late summer of 1945, carrying out tests of an improved radiometer at the 100-inch telescope. Dr. Lawrence H. Aller, of the Kirkwood Observatory of Indiana University, studied spectroscopic plates from the Mount Wilson Observatory files in the summer of 1945. In particular, he investigated the spectra of 10 Lacertae and of 14 peculiar "silicon" A stars. Direct photographs of several nebulae were taken by Dr. John C. Duncan, Director of the Whitin Observatory. Dr. Jesse L. Greenstein, of the Yerkes Observatory, spent a few weeks in Pasadena investigating the spectrum of υ Sagittarii in collaboration with Adams and Merrill. Mr. W. C. Miller, of Pasadena, has continued his observations of the spectra of emission-line

stars with the 10-inch and 60-inch telescopes. Of special value is his series of spectrograms of the "iron star" XX Ophiuchi. Dr. P. Swings has devoted a portion of his time throughout the year to investigations at the Observatory. These studies have been concerned chiefly with molecules and their relation to astrophysical problems. Miss Suzanne van Dijke, Fellow of the National Research Council, spent most of the year at the Observatory continuing her investigation of the differences between giant and dwarf stars of class M with the aid of high-dispersion coudé plates. In cooperation with Nicholson and Miss Richmond, Dr. Oliver R. Wulf, of the United States Weather Bureau, has made studies of magnetic records for possible correlations with storm patterns.

Instrument Design and Construction

Design: Edgar C. Nichols, chief designer; Harold S. Kinney, draftsman.

Optical Shop: Don O. Hendrix, superintendent; Floyd Day, optician.

Instrument Shop: Albert McIntire, superintendent; Elmer Prall, instrument maker; Fred Scherff, Oscar Swanson, Albert Labrow, Donald Yeager, machinists; Harry S. Fehr, cabinet maker.

Maintenance and Operation

Office: Anne McConnell, bookkeeper; Dorothea Neuens, stenographer and telephone operator.

Operation: Ashel N. Beebe, superintendent of construction; Kenneth de Huff, Sidney A. Jones (on leave of absence for military service), engineers; Thomas A. Nelson, Hobart Wright, Clarence H. Daily, Boyd Thompson, Ralph E. Bennewitz, night assistants; Emerson W. Hartong, truck driver and machinist helper; Anthony Wausnock, Mrs. Wausnock, Mrs. Pauline Byers, stewards; Arnold T. Ratzlaff, Homer N. Joy, Charles Dustman, Irving Angel, Harry Sering, janitors.

Sidney Jones resigned on January 1, 1946, after fifteen years of efficient service as engineer on Mount Wilson.

Several of those whose names are listed above have been with the Observatory for only a part of the year. In addition, numerous temporary employees have assisted in construction and repair work.

OBSERVING CONDITIONS

Since many of the staff were still on leave for defense activities during the fall of 1945, it was impracticable to maintain the full observing schedule with the 60-inch telescope. The monthly record of observations is, therefore, omitted. Solar photographs were obtained on 326 days between July 1, 1945 and June 30, 1946. During the same period, the 100-inch telescope was used on 283 nights.

The total snowfall was 30.5 inches, and the precipitation for the year was 33.73 inches, as compared with a normal amount of 38.00 inches.

SOLAR RESEARCH

Solar Photography

Solar photographs were made on 326 days between July 1, 1945 and June 30, 1946, by Hickox, Hoge, Nicholson, and Richardson. The numbers of photographs of various kinds were:

Direct photographs	652
Hα spectroheliograms of spot groups, 60-foot focus	1,000
Hα spectroheliograms, 18-foot focus	1,280
K2 spectroheliograms, 7-foot focus	16,302
K2 spectroheliograms, 18-foot focus	1,272
K prominences, 18-foot focus	1,248

Sunspot Activity

The magnetic classification and study of sunspots and related phenomena have been continued by Nicholson and Mrs. Mulders. Cooperative programs have been carried out with the United States Naval Observatory, the Observatory at Kodaikanal, and the Department of Terrestrial Magnetism of the Carnegie Institution.

During the calendar year 1945, sunspot activity increased considerably. Observations were made on 323 days. Only 12 days were without spots, as compared with 123 in 1944. The total number of sunspot groups observed in the overlapping new and old cycles was 220, as compared with 72 in 1944. The number of groups belonging to the new cycle increased from 52 in 1944 to 212 in 1945: the number in the northern hemisphere increased from 19 to 71; in the southern hemisphere, from 33 to 141. The number of groups belonging to the waning cycle decreased from 20 in 1944 to 8 in 1945: the number in the northern hemisphere decreased from 8 to 1; in the southern hemisphere, from 12 to 7. The last spot of the old cycle appeared on August 8, existing for one day only.

The monthly means of the number of groups observed daily during the past two and one-half years are given in the accompanying table.

The outstanding feature of solar activity was the huge sunspot group which appeared at the east limb of the sun on January 29, 1946. This group, with an area of 5400-millionths of a solar hemisphere, was the largest ever photographed. After February it decreased in area. It was last seen on May 8, 1946, at the west limb of the sun. Many excellent direct photographs of this group were obtained in addition to exposures with the spectroheliograph and the spectrograph.

Since 1800, the amplitudes of the sunspot cycles have been alternately high and low, the last cycle having been an active one. If this alternation continues, the present cycle will be less active than the preceding one, although during 1945 and the first half of 1946 spots have been more numerous than during the corresponding interval after minimum in the preceding two cycles. During the past century and a half the average sunspot cycle measured from minimum to minimum has been 11.2 years, although the last three cycles have been 10.0, 10.2, and 10.4 years, respectively.

Month	Daily number		
	1944	1945	1946
January	0.3	2.5	4.2
February	0.1	1.1	7.7
March	1.1	1.9	6.7
April	0.1	2.8	7.1
May	0.2	3.6	7.2
June	0.7	3.8	7.3
July	0.6	4.4	. .
August	2.1	2.8	.
September	1.1	3.6	. .
October	2.1	5.7	. . .
November	1.3	5.1	.
December	2.4	2.9	. . .
Yearly average	1.0	3.4	. .

Sunspot Polarities

Magnetic polarities in each spot group have, so far as possible, been observed at least once. The classification of groups observed between July 1, 1945 and June 30, 1946 is indicated in the table on page 8. "Regular" groups of the new cycle in the northern hemisphere are those in which the preceding spot has S (south-seeking) polarity and the following spot N polarity; in the southern hemisphere the polarities are reversed. For spot groups

Hemisphere	Polarity					
	Regular		Irregular		Unclassified	
	Old cycle	New cycle	Old cycle	New cycle	Old cycle	New cycle
North	1	92	0	0	0	39
South	2	124	0	1	1	65
Whole sun	3	216	0	1	1	104

of the old cycle, the distribution of magnetic polarities is opposite to that just described for the new cycle.

Richardson has completed a statistical investigation of spot groups of irregular magnetic polarity observed at Mount Wilson from 1917 to 1944. Spot groups of irregular polarity consistently include 2.5 per cent of the whole number classified during a cycle. The results indicate that irregular spot groups are as stable as those of regular polarity. There is no significant difference between regular and irregular groups in size or duration.

Comparison of the frequency of occurrence of regular and irregular groups throughout the cycle shows that the irregular groups are most frequent six months after the general sunspot maximum and that the proportion of irregular groups is greater after maximum than before.

For the two cycles 1923–1933 and 1933–1944, in both northern and southern hemispheres, the irregular groups first appeared about 5° farther from the equator than the regular groups, attained nearly the same mean latitude when the cycle was 70 per cent over, and had a mean latitude slightly lower than that of the regular groups at the close of the cycle.

It should be emphasized that these results have been obtained for the most part from the two cycles 1923–1933 and 1933–1944. Owing to the unpredictable character of sunspot activity, it should not be assumed that irregular spot groups will necessarily behave this way in future cycles.

Flares

The great sunspot group first seen on January 29, 1946 provided an exceptional opportunity for a study of the spectral characteristics of solar flares. Of several dozen flares observed by Richardson, two were outstanding for their brilliance and unusual motion.

The first was observed on February 11 at 0010 GCT at longitude 65°W. The yellow helium line, D3, λ5876 showed first as a weak absorption line but rapidly changed to emission. Eventually the intensity of D3 emission exceeded by 50 per cent that in the continuous spectrum of the surrounding photosphere. The line was broad, its width corresponding to a Doppler velocity of 36 km/sec and a displacement of the center equivalent to a velocity of recession of 7 km/sec.

The other brilliant flare was observed on February 27, 1946, when the spot group was approaching the east limb for the second time. More than 100 emission lines were observed in the spectrum from λ3960 to λ5900, including lines of ionized iron, titanium, barium, scandium, and chromium, as well as the more usual hydrogen, helium, and ionized calcium. The D3 and $H\beta$ lines had a width corresponding to

144 km/sec and a mean velocity of approach of 6 km/sec; the D lines of sodium had a width of 62 km/sec and a displacement of the center corresponding to a velocity of approach of 5 km/sec. The line λ4924.779 of *Fe* I, which was representative of the weaker lines, was narrower (width about 30 km/sec) and showed a mean velocity of recession of about 3 km/sec.

Prominences

Five eruptive prominences were measured by Pettit, bringing to 75 the total number catalogued. A portion of the eruptive prominence of February 28, 1946, connected with the great sunspot of that date, traveled in a straight-line trajectory, which when projected backward missed the solar surface by 50,000 km.

In addition to these recent observations, statistical studies have been made of all eruptive prominences catalogued up to the present time. The following are the most significant conclusions: (1) Eruptive prominences have been found in all latitudes between N 75° and S 76°, with strong maxima between N 20° and N 30° and between S 20° and S 40°. Forty-one per cent were found in the northern hemisphere and 59 per cent in the southern. (2) The observed duration ranges from less than 10 minutes to more than 8 hours. (3) The distance traveled has varied from 25,000 km to a solar diameter, with velocities ranging from 2 to 758 km/sec. (4) Except for the prominence of February 28, 1946, trajectory angles varied from 0° to 63° with a strong preference for small angles.

The Doppler effect was first applied to the determination of the rate of rotation of a tornado prominence by Pettit and Richardson on October 4 and 5, 1945. The measurements yield rotational periods of 2.5 to 3.5 hours.

The Solar Spectrum in the Photographic Infrared

Wave lengths, intensities, and descriptive notes have been completed for the entire table of infrared solar data, λ6600 to λ13495, by Harold D. Babcock and Charlotte E. Moore. The text to accompany the table is nearly complete and only a few additional identifications of solar lines await final settlement.

The scope of this collaborative work, which was begun in 1925, has been enlarged to include extensive data from the *Revised Multiplet Table,* by Charlotte E. Moore, and to utilize solar spectrograms not obtainable until last year. The work is primarily a description and interpretation of the spectrum of the center of the solar disk, with some discussion of integrated sunlight and of light from the solar limb. A notable addition relates to the spectra of sunspots in the range λλ6600–11404. Technicalities of interpretation are dealt with in numerous notes.

The table includes nearly 7350 lines, more than a third of which are telluric and thus potentially affect the observation of all infrared celestial spectra. Since the solar data are in general superior to existing laboratory measurements beyond the visible red, both in richness and in accuracy, they may be expected to facilitate the study of stellar spectra. It even becomes feasible to improve earlier analyses of some arc spectra, such as those of carbon, silicon, and magnesium, by the use of these solar observations.

Intensities of solar lines from λ6600 to λ11000, except those weaker than 1 on the Rowland scale, are calibrated in terms of equivalent width.

For several hundred lines of atmospheric oxygen, the isotopic combinations and the molecular vibrational assignments are given. Rotational designations are omitted for lack of space.

Ultraviolet Solar Spectrum

From λ2914 to λ3060, the identification of solar lines by Miss Moore has been made as definitive as the data permit. Two-thirds of the 550 lines now tabulated have been identified, many of them with more than one element. As would be expected, singly ionized atoms are well represented, more than one-half of the identifications being of this kind. Since most of the observed lines are blends, intensity relations in multiplets are often apparently abnormal and the solar wave lengths represent "mean" positions of their components, with resultant difficulty of interpretation.

Bands of Atmospheric Oxygen

Some additions have been made to existing data on O_2 bands beyond λ10000. With a dispersion of 2.4 A/mm, new details have been observed in the $^1\Delta \leftarrow {}^3\Sigma$ bands, revealing peculiarities of structure associated with this electronic transition.

General Magnetic Field of the Sun

One series of spectrograms has been made with the Lummer plate, using lines in the green region. Little measurement of the plates on hand has been possible, and no final conclusions are warranted as yet.

PLANETARY INVESTIGATIONS

The positions of Jupiter's satellites J VI, VII, VIII, IX, X, and XI were measured by Nicholson on photographs made with the 60-inch and 100-inch reflectors. Miss Richmond assisted in the measurement and reduction of the photographs. The first visual observation of J XI was made on May 7, 1946, with the 100-inch telescope, under excellent seeing conditions. The photographic magnitude was then 18.8, the visual magnitude perhaps one magnitude brighter.

STELLAR INVESTIGATIONS

Parallaxes

Prior to his death in January 1946, van Maanen completed the measurement of the parallaxes of 28 stars in 25 fields. In the list, recently published, are two stars with absolute magnitudes 15.0 or fainter: L1305-10, +15.4, and Ross 486B, +15.6.

This work completes the measurement of parallaxes in 500 fields and brings to a logical conclusion one of the major programs of the Observatory during the past thirty years. This program has been very fruitful in showing that large reflectors are useful for exacting astrometric measurements and in extending our knowledge of the motions, distances, and intrinsic luminosities of the nearer and fainter stars. The field, however, is limited, and no immediate continuation of this work is contemplated.

Color Photometry and Standard Magnitudes

The program for the investigation of the magnitudes and the colors of stars has been continued by Seares and Miss Joyner. The reduction of the Cape basic magnitudes to the International system reported last year has been confirmed by additional observations made at the Cape Observatory. A communication from Dr. R. H. Stoy states that the corrections required by the Cape photographic magnitudes are substantially those found at Mount Wilson. Since the spectrum-color relation based on the Mount Wilson reduction of the original Cape data is normal and independent of magnitude, the reduced photovisual magnitudes must also be close to the International scale. The conclusion that we now have a reliable photometric con-

nection of the two hemispheres is hereby greatly strengthened.

Photoelectric Photometry

The photoelectric measurements of 238 stars of different spectral types by Stebbins and Whitford, mentioned in last year's report, have since been published. About 40 additional stars of spectra G and K have been measured to provide a better determination of the effect of absolute magnitude, which makes supergiants distinctly redder than ordinary giants. Of the three characteristics, spectral type, absolute magnitude, and color index, it is the spectral type, because of the uncertainty in the classification, that gives the most difficulty in determining one of these characteristics from the other two.

Six-color measurements of the Pole Star have shown that the amplitude of variation ranges from 0.17 mag. at λ3530A to 0.04 mag. at λ10300A, which happens to be 1/9 of the corresponding variation of δ Cephei, the prototype of this class of variable star. Similar observations are being continued of other variables such as η Aquilae and RR Lyrae.

Among the new developments in photocells in recent years has been the RCA 1P21 multiplier tube, which promises considerable advance in the measurement of faint objects. Stars and nebulae of the fifteenth magnitude which were difficult to measure with a Kunz potassium-hydride cell on the 100-inch telescope should now be easy with the new multiplier.

Visual Magnitudes of Double Stars

The program for the visual measurement of the magnitudes of double stars with large magnitude differences has been continued by Pettit. Double images of the artificial star formed by the photometer have been eliminated by the use of a pellicle 3 microns thick. The equipment subjects the artificial star to the same scattered light as the component of the double which is measured. In previous measurements the effect of scattered light has been to make the faint component appear too faint. This has led to errors in the catalogue magnitudes. Thus, Aitken's P.G.C. No. 15514 with separation 1".08 records magnitudes 9.4 and 13.4. The present measurements give 9.79 and 12.15. No. 13596 with separation 2".75 has catalogue magnitudes 6.0 and 14.0, whereas three sets of measurements with the new equipment give 5.98 and 11.85. During the year, 148 sets of measurements of double stars, referred to Harvard Standard Regions, have been obtained.

Visual Magnitudes of Novae

Measurements of Nova Puppis (1942) have been continued by Pettit with the revised wedge photometer attached to the 20-inch reflector. The star faded from 10.47 mag. on October 18, 1945 to 10.84 mag. on March 8, 1946.

T Coronae Borealis (Nova 1866) has been measured on 62 nights since it was found by Armin Deutsch to have reentered the nova state recently, its magnitude on February 9, 1946 being 3.2. The interval between primary maximum and the beginning of the rise to secondary maximum was the same in 1946 as in 1866, with a possible error of 2 or 3 days. Both primary minimum and secondary maximum seem to be 0.1 or 0.2 mag. fainter in 1946 than in 1866, and the primary maximum was also probably fainter in 1946. When corrected for the companion star of magnitude 10.2, the light-curve shows that the primary minimum was actually 11.1 between May 8 and May 18, after which the rise to secondary maximum began and

the star increased in light 3.1 mag., reaching 8.0 on July 1. Pronounced secondary maxima of long duration are characteristic of slow novae. T Coronae Borealis is the only fast nova in which a pronounced secondary maximum has been observed. Some evidence of short-period fluctuations in light was found, particularly between May 30 and June 2, U.T., and on June 15, U.T.

Diameter of a Star from Occultation by the Moon

In continuation of his success in 1938, Whitford has observed an occultation of a star by the moon with a photoelectric multiplier and cathode-ray oscilloscope connected with the 100-inch telescope. According to theory, a point source at the moon's edge produces a diffraction pattern which sweeps by an observer on the earth in something like one-fiftieth of a second. A star of an appreciable angular diameter gives deviations from the pattern of a point source which can be recorded with the equipment used. At its occultation on June 6, the fourth-magnitude star ν Virginis, of spectral type M1, was observed to have a diameter of 0".008, which, combined with the spectroscopic parallax of 0".011, gives a real diameter of about 3/4 astronomical unit, in good agreement with the expected diameter of a star of this brightness and temperature. The method is applicable to about a dozen other stars of similar late spectral type when occulted by the moon.

Motions of Near-by Stars

Strömberg has made a study of the motions of all the stars within 20 parsecs of the sun having known parallaxes, proper motions, and radial velocities. The three velocity components of 444 stars were computed and analyzed. The velocity ellipsoids showed a general increase in group motion with the velocity dispersion, a consequence of the now well established asymmetry in stellar motions.

Attempts were made to establish correlations between the masses of the stars and their motions. The masses of the stars were estimated from their bolometric magnitudes. A slight tendency toward equipartition of energy was found in the velocity components perpendicular to the galactic plane. The motions in the galactic plane showed correlations indicating that the more massive a star is, the greater is the chance that it moves in an exact circle around the center of the galaxy. This relationship has been interpreted as due to the effect of viscous forces acting when the stars in the galaxy were in the process of formation.

STELLAR SPECTROSCOPY

Taurus Cluster

The spectrographic survey covering all the stars brighter than 10.5 visual magnitude which have been suggested as members of the Taurus cluster has been completed by R. E. Wilson. Radial velocities of 194 stars have been determined. With the earlier observations at Mount Wilson and elsewhere, we now have radial velocities of 260 stars in this region which have proper motions close in size and direction to those of the brighter stars defining the cluster. These studies indicate that 150 stars are cluster members, 13 are probable members, 26 are possible but doubtful, and the remainder are definitely not members.

The vertex of motion of the cluster, derived from *General Catalogue* proper motions of 77 of the stars, lies at A =

94°0; D = +7°6. The stream motion is 44.2 km/sec. The actual motion of the cluster within the stellar system is toward an apex at A = 96°5; D = +27°1, with a speed of 30.9 km/sec.

The mean distance of the cluster is 41.5 parsecs. It is flattened toward the plane of the Milky Way and elongated in this plane along a direction running through the galactic center. The absolute magnitudes of the individual members were computed from the observed proper motions. The distribution of absolute magnitude with spectral type agrees well with that of the stars with the best-determined trigonometric parallaxes.

Radial Velocities

An extensive program for observation of radial velocities has been carried out by R. E. Wilson with the one-prism spectrograph on the 60-inch telescope. About 1000 plates have been taken during the past year. In addition to the Taurus cluster, already mentioned, groups of objects observed include stars with appreciable proper motion, M-type stars, double stars, and other special objects.

The determination of the velocities and spectral classification of 180 dwarf stars with proper motions greater than 0".35 has been completed by Joy, and the material is being prepared for publication.

Radial Velocities of o Ceti

A series of plates of o Ceti taken by Merrill and Joy with the coudé spectrograph from October 1945 to February 1946 covered the increase in light from minimum to maximum. Unfortunately, the light-curve proved to be peculiar in some respects and the maximum was fainter than normal. The velocity-curve and spectral changes also showed peculiarities which require further study. It is evident that at certain cycles the behavior of the star is quite abnormal.

Long-Period Variable Stars

During the past year extensive measurements with a dispersion of 10 A/mm have been made by Merrill in the spectra of six long-period variable stars of class Me; U Orionis, R Serpentis, R Aquilae, and R Cassiopeiae were discussed briefly, R Hydrae and R Leonis in more detail.

Dark lines. The spectral region from *Hδ* toward the ultraviolet is especially favorable for the study of atomic lines because it is rich in lines of many metals and because the interference of molecular bands is very slight. The spectrum of R Leonis, a star near the lower end of the temperature sequence, was photographed into the ultraviolet as far as λ3450.

The spectral lines of the metallic elements *K*19 to *Ni*28, inclusive, were studied in considerable detail; other elements measured included *Mg, Al, Sr, Y,* and *Zr.* Because of the low temperature, lines arising from levels with excitation potentials less than 0.5 volts are predominant. The displacements of lines from the ground level are algebraically smaller by 3 or 4 km/sec than are those of lines of excitation potential 1.6 volts. The mean velocity derived from the dark lines seems not to exhibit characteristic variations with phase like those in a spectroscopic binary or a pulsating star.

Bright lines. The behavior of emission lines of hydrogen and several other elements is of special interest because the presence of these lines in a low-temperature spectrum, although anomalous, has a bearing on a general problem of considerable astrophysical importance, namely, the widespread occurrence in astronomical sources of emission lines requiring far higher excitation than that corresponding to thermal equilibrium.

The relative intensities and the general behavior of the bright lines of several metals are not easy to understand. In one instance in the iron spectrum, the dependence on a particular energy level quite supersedes the ordinary multiplet relations. In several stars, after maximum light, diffuse emission lines appear on the short-wave-length sides of the dark H and K lines of ionized calcium, and as the cycle advances become quite striking. They present the anomaly that the line at H is considerably more intense than that at K.

Velocity-curves of various groups of lines show decided differences. The patterns in o Ceti, R Hydrae, and R Leonis, however, have much in common. The complex spectroscopic behavior characteristic of Me variables is thus gradually being determined in greater and greater detail.

Variables of class Se. Spectrograms and measurements have been obtained for comparable studies of R Andromedae and χ Cygni.

Spectrographic Studies of Variable Stars

Observations of AE Aquarii to determine the period of the velocity changes have been continued by Joy, but no light-maxima have been seen.

Observations of RR Lyrae and RV Tauri variables and the long-period variables in globular clusters have been continued. Additional spectrograms of the eclipsing variables RW Tauri and S Cancri have been obtained at minimum light.

Sanford has made extensive observations with the coudé spectrograph of Cepheid, cluster-type, eclipsing, and red variables.

Spectroscopic Studies of Novae

Sanford has made systematic observations of the spectrum of Nova T Coronae Borealis since it reached its maximum, in February 1946. It has been possible to obtain spectra with the coudé spectrograph of the 100-inch telescope even when the nova was as faint as $M_v = 9.7$; the dispersion is 10 A/mm in the blue, and 20 A/mm in the red. A number of spectrograms extend to λ3400 in the ultraviolet, and one spectrogram is well exposed over the region λλ5800–8700. These relatively high-dispersion spectrograms of Nova T CrB are especially valuable in resolving close emission lines, in revealing details of the changes in the absorption components accompanying emission lines, and in determining relatively accurate radial velocities from both emission and absorption lines. The spectrum is always complicated and has undergone many radical changes since the February maximum. The radial velocity derived from the class-M spectrum increased steadily from about −46 km/sec in mid-March to −2 km/sec in mid-June. Observations will be continued in order to follow not only the emission-line changes, but also the radial-velocity variations for the class-M spectrum.

Studies of the spectra of Nova Puppis 1942 and Nova Aquilae 1945 were completed by Sanford during the year.

Faint Blue Stars

Spectroscopic observations of faint blue stars of photographic magnitude 12.5 to 15.2 found by Zwicky with the Schmidt telescope on Palomar have now been completed by Humason. Fourteen of these stars are in the Hyades and have spectral types ranging from Bo to B5. From their proper motions and spectra, four are white dwarfs; two others have spectra similar to that of a white dwarf. Spectra of seven of the remaining stars do not correspond to that of normal B stars. The peculiarities may be due to rotational widening or they may be an indication that the stars are subdwarfs.

Thirty-one stars of spectral types Bo and Ao were observed in the region of the north galactic pole. Of these stars, 3 seem to be white dwarfs, whereas the spectra of the other 28 appear to be normal. If these 28 stars are high-luminosity blue stars, their distances are exceedingly large; it is assumed, therefore, that they belong to the type of stellar population shown in the Hertzsprung-Russell diagram for globular clusters and designated as type II by Baade. Their absolute magnitudes are then close to 0.0, and we should expect to find them, like the globular clusters and cluster-type variables, scattered thinly in all directions, forming an almost spherical system.

Faint Stars with Bright Lines in the Taurus Clouds

In a search for additional stars with T Tauri characteristics, three objective-prism plates taken by Mr. W. C. Miller with the 10-inch refractor were examined by Joy. A total of 40 stars with *Hα* in emission was found, of which 29 were checked with slit spectrograms. Their magnitudes, with two exceptions, were between 11.5 and 14.5. Three showed spectra near Ao; 8 resembled the T Tauri stars with very strong, bright *H* and *Ca* II, together with bright *Fe* I (λ4063 and λ4132), *Fe* II, *He* I, and [*S* II]. The other spectra are dKoe–dM4e with bright *H* and *Ca* II, and occasionally show weak *He* I and *Fe* II emission. The relation of these stars to the dMe stars having large proper motion and low luminosity is not yet clear. Like the T Tauri stars, these new bright-line objects have a tendency to congregate on the outskirts of areas of obscuration.

Early-Type Stars with Emission Lines

On the objective-prism photographs taken by Mr. Miller, about 180 additional bright-line stars have been discovered by Merrill and Miss Burwell, and many others are suspected. Forty of them have been observed with a slit spectrograph.

Slit spectrograms of about 40 previously catalogued Be stars have been obtained by Merrill and Miller. Observations of several of the more interesting stars are being extended over a term of years.

Spectra of "Silicon" A Stars

Aller has analyzed the spectrograms of 14 "silicon" A stars characterized as "peculiar." In the Aop stars, the 3933 *Ca* II line shows a great range in intensity from object to object; lines of other elements show less spectacular variations. Although the number of hydrogen atoms above the level of the photosphere appears to be the same as in the ordinary Ao-type stars, such as Sirius or γ Geminorum, the quantity of the metals is greater by a factor of 10 or more. For most of these stars the profiles of the hydrogen lines are narrower than in typical dwarfs, but broader than in supergiants such as α Cygni. The possibility that one may be dealing with shells, as has been suggested by Weaver for certain A-type stars in clusters, must be examined. The profiles of the hydrogen lines, however, give no clear evidence for the existence of shells.

Wolf-Rayet Stars

The spectra of Wolf-Rayet stars are being investigated in the infrared by Minkowski. The spectra of WC stars are somewhat richer in lines than those of the WN stars. Both types show with good intensity the *He* II lines corresponding to the Pfund series of *H* with the lower level $n = 5$. O. C. Wilson is making a survey of all readily observable Wolf-Rayet stars in order to obtain statistical data concerning the percentage of binaries among them.

Spectra of Individual Stars

The 114-inch camera of the coudé spectrograph of the 100-inch telescope yields a dispersion of 2.9 A/mm. This high dispersion makes possible detailed study of even the more complex stellar spectra. Several such studies are nearing completion.

Adams and Merrill have cooperated with Dr. Jesse L. Greenstein, of the Yerkes Observatory, in a detailed investigation of the spectrum of υ Sagittarii. A description of the infrared part of the spectrum is ready for publication. Adams has made further measurements of supergiant M-type stars, such as α Orionis, which show shell-like characteristics in their spectra.

Mrs. Locanthi is preparing a complete table of the wave lengths, intensities, and identifications of over 10,000 lines in the spectrum of β Pegasi in the region λλ3400–8600.

The characteristics of two typical class-M giant and dwarf stars are under investigation by Miss van Dijke. Differential line intensities for the giant and dwarf have been determined visually for approximately one thousand lines. Estimates of absolute line intensities for the giant star have been obtained from comparisons with the spectra of the sun and Arcturus. A study of the behavior of the various atoms at different excitation potentials is under way, and curves of growth for the two class-M stars are being constructed to determine the relative abundances, temperatures, and electron pressures.

Stellar Spectra in the Infrared

Exposures of a few bright stars have been made by Sanford in the spectral range beyond λ10000. Satisfactory spectra were obtained for α Orionis, α Scorpii, and α Boötis extending to the region just beyond λ11000, where the stellar spectra are masked by atmospheric bands. Spectrograms of even the brightest available early-type stars will require exposures that are very long relative to the exposure time for stars of late type.

General Magnetic Field of Early-Type Stars

The large rotational velocity attributed to A-type stars, in comparison with that of the sun, suggests the possibility that a relatively large general magnetic field may exist in these objects. Stars of type A showing sharp lines, and therefore probably having an axis of rotation nearly parallel to the line of sight to the earth, appear to be the best objects for a test of this hypothesis. With a right- and left-handed analyzer on the coudé spectrograph, H. W. Babcock has obtained a number of spectra of objects of this type. Preliminary measurements of the spectrum of 78 Virginis suggest a value of 1600 gauss for the polar field strength of this star, whereas check runs on a K-type star show no measurable field.

GALACTIC NEBULAE AND STAR CLOUDS

Survey of Planetary Nebulae

The search for planetary nebulae by Minkowski is nearing completion, 75 having been found prior to July 1, 1946. The program consists in locating and classifying all objects which show *Hα* emission with little or no continuous spectrum on objective-prism plates. It is already evident that the planetaries are highly concentrated toward the center of the galactic system. This distribution is significantly different from that of the O- and B-type stars and

of the Wolf-Rayet stars. Furthermore, the distribution, together with the fact that a planetary is known to exist in a globular system (M 15), seems to indicate that planetary nebulae belong to Baade's star population of type II (typical of globular clusters).

Infrared Spectra of Planetary Nebulae

Together with L. Aller, Minkowski has photographed the spectrum of a planetary nebula, NGC 7027, in the infrared with the aid of the greatly improved Eastman IN emulsion. In the region above λ6700, the spectrograms show the continuous spectrum of the nebula, in addition to numerous emission lines. A spectrophotometric investigation of the spectrum is under way.

Expansion Velocities of Planetary Nebulae

A study of the velocities of expansion of the brighter planetary nebulae is being made by O. C. Wilson, using the coudé spectrograph of the 100-inch telescope. In nearly all objects observed so far, the lines have the characteristic shape to be expected from an expanding shell. Interesting differences in the velocity of expansion have been noted between the lines of various degrees of ionization and excitation. In general, the lines of higher excitation have apparently smaller velocities of expansion.

The Nuclear Region of the Galactic System

Knowledge of the nucleus of the galactic system, including comparison with nuclei of other stellar systems, is very desirable. The galactic nuclear region is dimmed by heavy general obscuration, and the nucleus itself is hidden behind one of the dark clouds which outline the "star clouds" of the Milky Way. For these reasons, the identification of a part of the "nuclear bulge" by Baade represents a significant advance in the study of galactic structure.

The extremely high stellar densities previously found on red exposures of the Sagittarius star cloud suggested strongly that this cloud is a part of the galactic nucleus. In order to test this hypothesis, the field around the globular cluster NGC 6522 (Gal. long. = 328°; gal. lat. = −4°), about 5° from the presumed position of the nucleus, has been searched for variable stars on plates taken with the 100-inch telescope.

Although the search is still incomplete, the results confirm the unusual character of the star cloud. The number of variables per square degree—more than 400—surpasses by a factor of at least 30 the numbers found in Milky Way fields previously investigated. Even more significant is the fact that the great majority of the variables are of the cluster type, which normally contributes only a negligible percentage of the variables found in low-latitude fields. Finally, these variables are all at approximately the same distance. Very few have maxima as bright as the sixteenth magnitude; most of them appear between 16.5 and 18.0, after which they fade out rapidly.

A provisional determination of the apparent distance modulus of the cloud leads to $m - M = 17.3$. This value, when corrected for absorption as indicated by the color excess ($E = +0.37$ on Stebbins' C1 system, for NGC 6522, which appears to be a member of the cloud), leads to a true modulus of $m - M = 14.7$, or a distance of 9 kiloparsecs. The provisional data make it highly probable that the bright Sagittarius Cloud is a part of the nuclear bulge of the galactic system, and that this nucleus, like the central region of the Andromeda nebula, is composed of stars of type II.

EXTRAGALACTIC NEBULAE

Emission Nebulosities in M 31

The detailed study of the Andromeda nebula (M 31), as one of the most accessible of the neighboring spirals, has been continued by Baade. As was mentioned in last year's report, the spiral contains numerous emission nebulosities which, although weak in the photographic region of the spectrum, are conspicuous on *Hα* plates. In view of the importance of these objects for the study of the rotation—and hence the dynamics—of the spiral, a systematic survey has been initiated, using plate-filter combinations covering the two neighboring regions of the spectrum, λλ6400–6700 and λλ6700–7300. The first of these contains *Hα*, but the second is free from nebular emission. By "blinking" the pairs of plates, emission patches are readily identified even when they appear semi-stellar.

The necessary exposures for the areas preceding and following the nucleus of the spiral were obtained during the past year. On these plates, 150 emission patches have been recognized, which, it is interesting to note, are restricted to the spiral arms.

Diameter of M 31 from the Distribution of Stars

Baade has also redetermined the diameter of M 31 from the distribution of individual stars, for comparison with the discordant photometric estimates published in recent years. An area along the south preceding major axis, 81′ wide, extending from 45′ to 179′ from the nucleus, was covered by one-hour exposures under good conditions with the 100-inch telescope, a number of ultraviolet exposures being included to check the colors. The results indicate that, beyond the area covered by the well known reproductions of Yerkes and Lick photographs, three more spiral arms follow, each fainter and less populous than the preceding one. The last of these arms crosses the major axis about 116′ from the nucleus. Both scattered groups and individual blue stars of the nineteenth and twenty-first magnitudes can be followed out to about 150′ (a very blue, open cluster at 151′ offers a convenient limit marker).

These data indicate that the diameter, as derived from B stars and open clusters, is about 5°, or in linear measure about 20 kiloparsecs. Since the diameter of the galactic system, based on the same types of objects, is about 24 kiloparsecs (distance of sun from nucleus, 8 kpc; extension of the system of open clusters from the sun in the opposite direction, 4 kpc), it is evident that M 31 and the galactic system are closely comparable in size.

Red Shifts and Spectral Types

During the year, Humason has obtained about 70 small-scale (500 A/mm) spectrograms of extragalactic nebulae for red shifts and spectral types. The number of nebulae observed spectroscopically at Mount Wilson is now 500, for 146 of which the measures have been published. It is proposed to publish the data for the remaining 354 objects in the immediate future, together with a general discussion of the entire collection.

The collection is now considered sufficient for survey purposes, and further studies will be concentrated on special problems. The list is thoroughly representative of the nebulae brighter than the thirteenth magnitude, for which it covers the entire range of the sequence of classification. With diminishing brightness, the earlier types tend to dominate the list because of easier observing conditions, until among the faintest objects the E nebulae

alone are represented. In brightness, the list ranges from the Andromeda nebula to nebulae at the limit of visibility with the 100-inch telescope.

The Virgo cluster is represented by 66 members; the Ursa Major group, by 36; the Coma cluster, by 21; and several of the fainter clusters and smaller groups by 4 to 12 members each.

The Mount Wilson Collection of Direct Photographs of Nebulae

Analysis of the Mount Wilson collection of direct photographs of extragalactic nebulae has been resumed by Hubble, who has improved the collection by retaking poor plates. Special attention has been given to the resolution of late-type nebulae, to dwarf systems in near-by clusters and groups, and to variable stars in the nearest nebulae outside the local group. The major problems are: (*a*) the detailed study of the sequence of classification, including the correlation between structure and contents; (*b*) the fainter part of the luminosity function of nebulae; (*c*) the luminosity function of "brightest stars" in nebulae; (*d*) the continued search for individual stars of known luminosities, on which must rest the fundamental calibration of all criteria of extra-galactic distances.

Progress has been made on each of these problems, although, in general, definitive results must wait on the slow techniques of precision photometry. The observing programs have produced various by-products such as supernovae in NGC 3977 and NGC 4632, normal novae in M 81, variables in M 51 and M 101, and one variable of especial interest in M 33. This last object, one of the rare blue supergiant variables, has reached the brightest maximum attained by any of the four such variables recorded in the spiral over a period of 36 years. The star (5′.0 south preceding the nucleus of M 33) has brightened about 3 mag. over a period of years and is now about magnitude 14.5, or of the order of $M = -8$. It is now possible to study the spectrum on an adequate scale instead of on the very small scales used for two of the variables investigated previously.

LABORATORY INVESTIGATIONS

Work has been resumed by R. B. King on the measurement of relative *f* values of *V* I and *Ni* I lines from electric-furnace absorption spectra.

Additions have been made to the collection of band spectrograms of compounds which, when reduced to the scale of stellar spectrograms, have been found to aid in the identification of bands appearing in spectra of the late-type stars.

An attempt is being made to measure the relative transition probabilities of the main band heads in the Swan system of the carbon molecule C_2.

MAINTENANCE, OPERATION, AND NEW CONSTRUCTION

During the war years most of the new construction and even the repair work at the Observatory had to be held in abeyance. With the close of the war, however, it has been possible to embark on an extensive program of repair and modernization to extend over a two-year period. It is hoped that the completion of this program will bring the physical plant of the Observatory into first-class condition at the time when joint operation with the Observatory on Palomar Mountain is started.

The program involves many minor repairs and improvements and painting most of the Observatory buildings. The following major improvements deserve special mention:

1. Visitors' gallery for the 100-inch telescope. The completion of the paved road to Mount Wilson, prior to the war, has brought visitors to the Observatory in such numbers that it is no longer feasible to take them onto the floor of the dome of the 100-inch telescope. New arrangements now nearing completion are such that visitors can enter the dome by a separate entrance and pass through a glassed-in visitors' gallery. From the gallery they have a close-up view of the telescope.

2. Modernization of cottages and Monastery on Mount Wilson. Most of the living quarters on the mountain were completed early in the history of the Observatory and many of their facilities have become antiquated. Extensive improvements are planned in the plumbing and other features.

3. Photographic facilities on Mount Wilson. Refrigeration units are being placed in all darkrooms, and a cold-storage room for plates is being installed.

4. Direct intensity microphotometer. This is a microphotometer of a new type that plots directly the intensity to which the plate is exposed. This instrument, which is being designed by H. W. Babcock and Nichols, should greatly facilitate intensity studies, which are becoming of increasing importance in astronomical investigations.

Most of the new equipment for the Observatory is being designed by Edgar C. Nichols. The instruments are being constructed in the machine shop under the direction of Albert McIntire and in the optical shop under the direction of Don O. Hendrix. The repairs and new construction on Mount Wilson are being supervised by A. N. Beebe, with the assistance of Kenneth de Huff, engineer.

By the end of the year the shops had returned largely to Observatory work, but for the year as a whole over one-half of the shop time was spent on war construction.

THE LIBRARY

During the past year, 174 volumes have been added to the library, making a total of 15,782 in the collection. Of the gifts, a large proportion have come from Dr. Hale's scientific library; 37 volumes have been purchased, but only 62 volumes were bound because of difficult conditions still prevailing in the bindery. The number of periodicals and publications of observatories and learned societies received is still below normal, although European publications are arriving again, and some of the volumes of periodicals for the war years have come to complete the files. In order to provide a suitable place for the books from Dr. Hale's scientific library, an office adjoining the library has been added to the library rooms.

Before general distribution of the Observatory publications was resumed after the war, a questionnaire was sent in December 1945 to names on the old mailing list. A gratifying number of responses has been received.

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GEOPHYSICAL LABORATORY

Washington, District of Columbia

L. H. ADAMS, *Director*

After an interruption of more than five years, the Geophysical Laboratory has begun to turn its attention again to fundamental science, which during the war was laid aside completely in favor of research and development sponsored by the National Defense Research Committee. Although the main government contract pertaining to the long-range project was terminated at the end of December last year, certain responsibilities to NDRC required the services of many of the staff members through the early months of 1946; and it was not until near the close of the "report year," ending in June, that the staff members were able to give proper attention to the review of past work and the redefining of aims, as specified by President Bush. Their joint efforts have now made it possible to formulate the desirable objectives of future research at the Geophysical Laboratory; and it seems appropriate at this time to present an outline of the proposed program.

FRAMEWORK OF A PROPOSED PROGRAM FOR FUTURE RESEARCH

General Purpose of the Geophysical Laboratory

The original grant that led to the establishment of the Geophysical Laboratory was labeled for the "investigation of mineral fusion and solution under pressure." At an early date, the objective was somewhat broadened to cover other investigations aimed at establishing the conditions under which igneous rocks are formed in the earth. By inspection of the published record, it may be seen that, as researches branched out from one subject to others, the Laboratory ultimately covered a wide range of topics—doubtless too long and varied a list for effective treatment in one department of the Institution. What is called for now is a fresh start, a restatement of objectives, and the outlining of a compact program.

The field of interest of the Laboratory can be broadly described as experimental geology; and it is the practically unanimous feeling of those who, in recent months, have given thoughtful consideration to the matter that the Laboratory should continue in that general field. The training and experience of its staff members, as well as its background, facilities, and contacts, make it peculiarly well fitted for further work in this subject, in which much remains to be done. Furthermore, in undertaking originally to investigate mineral fusion and solution in a comprehensive way, the Laboratory may fairly be considered to have assumed an obligation to provide a quantitative basis for petrology. But, although it has provided something in the way of a foundation on which an understanding of igneous geology can be built, the existing inadequacy of our knowledge concerning the behavior of silicates in the presence of water and other volatile components constitutes an unfulfilled part of the early commitment.

In conformity with what has been agreed upon in the discussion among staff members, it is considered that *the general purpose of the Geophysical Laboratory is to learn as much as possible concerning the composition and nature of the earth as a*

whole and to understand the processes by which, during geologic ages, it reached its present state. A qualification that is meant to be implied in this statement is that primary attention should be given to the lithosphere, although, to be sure, the hydrosphere and atmosphere involve problems that touch upon the condition of the solid earth. It will be understood that, as in the past, the work of the Laboratory for the future would be described, in broad terms, as the application of physics, chemistry, and mathematics to a variety of problems involving (*a*) the genesis of igneous rocks, (*b*) metamorphic processes, and (*c*) the constitution of the earth, including its interior.

Principal Fields of Interest

For the purpose of translating the general program of the Laboratory into a series of experimental and theoretical procedures, and in order to permit the selection of the most important parts of the subject for investigation, it will be useful to divide the whole area into five major fields of interest as follows: (1) fusion relations; (2) thermal quantities; (3) volume changes; (4) other properties of minerals and rocks; and (5) volcanological and other field studies.

1. *Studies of fusion relations of minerals and of related equilibria*

Investigations on this general subject form one of the fundamental bases for interpretation of the problems of geology and geophysics. *For convenience,* the investigations may be subdivided in accordance with the geologic processes to which they pertain. It will be understood that the individual lines of investigation, consisting mainly of studies of equilibrium relations, cannot be classified strictly in these categories.

Orthomagmatic processes. The term orthomagmatic refers to processes that take place within a crystallizing magma, which may be treated as merely a complex silicate solution containing the principal rock-forming oxides. In addition to water —and exclusive of titanium oxide, which is not of primary significance in petrogenesis —the oxides present to the extent of 1 per cent or more in the earth's crust are eight in number, viz., SiO_2, Al_2O_3, Fe_2O_3, FeO, CaO, Na_2O, MgO, and K_2O. It has been found possible at the Geophysical Laboratory to acquire a considerable amount of information on the effect of temperature on the behavior of simple to moderately complex anhydrous combinations of the principal rock-forming oxides. It is essential to have additional data on "dry" silicate mixtures in order to complete our information on the composition of olivines, pyroxenes, and certain other minerals, and on the mutual stability relations of all the simpler rock-forming minerals. Further studies of anhydrous silicates also are an essential base from which to expand our knowledge of the effects of pressure and of volatile components. Experimentation that in the past has dealt mainly with melting and crystallization should, moreover, be extended to include the mutual stability relations at temperatures below which liquid is present.

Some results also have been obtained on the effect of pressure on single mineral substances and on a few mixtures; but most of this work has been carried out only at room temperature, and should be extended to elevated temperatures, if we are to approach the conditions existing in Nature.

Development of experimental techniques for the study of phase relations in mineral systems with water as a component has been slow, but progress has been made with a few substances at moderate temper-

atures and pressures. Unless these investigations can be extended to cover mixtures of the principal rock-forming oxides with water, we cannot hope to have a satisfying explanation of the origin of a large part of the igneous rocks. The amphiboles and micas generally contain water, and they are important rock-forming minerals. There is inadequate information on the composition ranges of these minerals, and little or no information exists as to the conditions of stability with respect to temperature and pressure, and the exact relations of these minerals to olivines, pyroxenes, melilites, feldspars, and feldspathoids, and to the liquids from which they crystallize.

Experimentation would consist in the determination of the effect of volatile components (at first water and later other volatiles), at a series of pressures, on the melting and mutual stability relations of silicate minerals and on a series of synthetic melts consisting of few components and having compositions varying from basic to acidic rock types, that is, from those in which silica and alumina predominate to those high in iron oxide and magnesia. Measurements would also be made of the solubility of water at a series of pressures in melted natural rocks of a wide range of composition, and studies would be made on crystallization in these hydrous melts.

Pneumatolytic processes. Minerals formed wholly or in part from gaseous compounds or gaseous solutions derived from the crystallizing magma are said to be of pneumatolytic origin. Knowledge of their equilibrium relations and their reactions with previously formed minerals would provide a much better understanding of this complex group of phenomena that lie, in time and temperature, between orthomagmatic processes and the hydrothermal formation of veins and ore deposits.

The pertinent laboratory experimentation would consist initially in the determination of the effect of temperature and pressure on equilibria in gaseous mixtures containing two or more of the following gases: hydrogen, oxygen, sulfur, carbon dioxide, chlorine, fluorine, hydrogen sulfide, and water vapor. Solubility measurements of nonvolatile components of vein minerals in highly compressed gases, especially water and water-rich mixtures, should be made; also exploratory studies of the effect of various gases singly and in combination on natural and synthetic minerals.

Hydrothermal processes: veins and ore formation. Hydrothermal processes are limited, by definition, to those involving hot aqueous solutions (liquid, not gaseous). In nature, there is a continuous gradation between pneumatolytic and hydrothermal processes; and the same gradation will naturally be found in laboratory studies. As a matter of fact, in a complete study of a pertinent system, such as, for example, a silicate-water one, all types of phenomena, from those analogous to orthomagmatic through those analogous to hydrothermal, can be encountered.

So many veins and ore deposits are definitely of hydrothermal origin that it is worth while to concentrate a certain amount of attention on hydrothermal phenomena as such. Experimental work bearing on these problems would include studies of conditions of formation and determinations of stability ranges for silicates and other vein minerals in aqueous solutions.

Metamorphic processes. A large proportion of the rocks as we see them today have been profoundly altered by heat and by pressures, usually in combination with the effects of liquid or gaseous materials. This important aspect of rock formation could be approached by experiments such as the determination of the mechanical and chemical effects of high pressures on rocks

and minerals, first without and then with water present, over the probable temperature range obtaining in Nature during rock deformation.

2. *Measurement of thermal quantities*

Existing information on specific heats, latent heats of fusion, heats of solution, and heats of reaction of rock-forming substances is wholly inadequate. Without reliable thermal data, it is difficult to make satisfactory progress toward the complete interpretation of rock-forming processes. Some of the important questions that have been raised in this connection are: What is the thermal mechanism of cooling and crystallization in a differentiating magma? Why do abrupt changes in the rate of cooling occur? What kinds of extraneous solid rock can a magma assimilate, and under what conditions? What thermal factors are important in metamorphism? What is the source of heat for igneous activity? What part does radioactive heat play?

The program should include measurements of specific heats and latent heats of melting and of transformation for silicate minerals; heats of solution and reaction of mixtures of two or more rock-forming oxides; and the measurement of specific heats, especially at very low temperatures, of silicate minerals and constituent oxides so as to determine indirectly (by thermodynamic principles) various equilibrium relations, including the conditions of temperature and pressure at which the minerals can exist as stable phases.

3. *Determination of volume and volume changes*

In order to take full advantage of some useful thermodynamic principles, it is necessary to have further determinations of the densities of minerals and of the volume changes during melting and other phase reactions, as functions of temperature and pressure, for the more important minerals and their mixtures.

4. *Investigation of other properties of minerals and rocks*

Consideration would need to be given from time to time to the measurement of a variety of properties that are involved in the formation and present condition of the earth. Some of the experimental investigations that need ultimately to be carried out are: further determination of elastic constants of minerals and rocks, especially at high temperatures and pressures; a study of the effects of temperature, pressure, and composition on the magnetic properties of minerals and rocks; measurement of the viscosities of liquid silicate mixtures; and the determination of ionic diffusion in minerals, and permeability of rocks and minerals to gases at various temperatures and pressures.

5. *Volcanological and other field studies, and related laboratory experimentation*

Among the field studies to which attention could profitably be given are: an exploration of subcrustal material by producing an artificial "earthquake" on an adequate scale, applying modern seismic techniques to obtain precise time-distance data and combining the derived velocity-depth results with information obtained from laboratory measurements on the elastic properties of rocks, so as to obtain a better knowledge of the constitution of the earth in the important range of fifty to one hundred miles below the surface; volcanological studies, including chemical investigations and the application of seismic, magnetic, electrical, and gravimetric methods to the study of the material underlying an active volcano; and the measurement of thermal gradients in a deep bore hole in an ancient crystalline complex. In addition, it is important to determine the

thermal conductivities and densities of the various rock specimens obtained from such a bore hole, and to make a similar study in a bore hole situated in a recent volcanic area.

These and other investigations involving field work, such as the collection of core samples from the ocean bottom in the deepest parts of the ocean, and gravimetric surveys in select areas on land and sea, are of vital concern to us in connection with other parts of our program; but many of the projects will require more facilities and manpower than this Laboratory is able to muster. As indicated below, some of the projects should, therefore, be on a cooperative basis, and for others we would act merely in an advisory capacity.

Priority of Specific Projects

In the general field of geophysics, the possible kinds of researches are so numerous that an organization of the size of the Geophysical Laboratory can deal adequately with only a relatively small part of the whole area. A careful selection of problems is therefore essential. For purposes of orderly attention, it will be convenient to divide the enterprises of principal concern to the Laboratory into three main groups, as follows:

Group I. Projects particularly suitable for carrying out by the Geophysical Laboratory at an early date—those that most nearly meet the criteria of being worth while and of not being readily undertaken elsewhere, and those that perhaps may justify a claim of being projects that the Laboratory is uniquely qualified to pursue.

It is hereby proposed that in this high-priority group we place investigations of two general kinds. The first may be described as consisting in laboratory studies bearing on magmatic processes. Some of the fundamental problems in this field have already been solved by the Laboratory, but others of great importance await solution. A concerted effort by more than one experimental approach should be made to define the conditions of equilibrium between crystals and liquids *in the presence of volatile components,* usually under pressure, and at first with water vapor and later with carbon dioxide and other gases. These investigations need to be carried on concurrently with the determination of solubility of water or water vapor in a variety of silicate magmas, temperatures being carried down to the point where crystalline phases appear. The melts should include those ranging in silica content from acidic to basic types. In addition, some further dry-melt studies should be undertaken, partly to form a foundation for the "wet" silicate determinations and partly to throw light on some important unanswered questions concerning magmatic processes, particularly those involving iron oxides. It will be especially important to find better means of controlling the state of oxidation of iron in mixtures containing ferrous and ferric silicates.

A major objective of this class of studies would be the elucidation of the conditions under which hornblende and mica, as well as other hydrous and anhydrous substances, separate from magmas. Investigations involving mineral formation from relatively dilute aqueous solutions should not be neglected. Although, for practical purposes, the investigations on (*a*) solubility of water in magmas, (*b*) crystal-liquid equilibria, and (*c*) formation of minerals from dilute solutions might be somewhat independent, they should be continually coordinated, because the hydrothermal solutions that deposit ore minerals are the solutions that deposit also the associated silicate and other gangue minerals. Studies of hydrothermal solutions are a

natural follow-up of studies of "wet" melts, just as in Nature the hydrothermal solutions come from "wet" magmas. Although referred to as a follow-up, studies of hydrothermal solutions in autoclaves would not need to await the results of studies of wet melts in "pressure furnaces." Indeed, the opposite might sometimes be true. That is, it might be advantageous to approach the study of the formation of hornblende and biotite from wet melts through investigations of the formation of simpler amphiboles and micas in autoclaves.

As a necessary adjunct to this part of the program, it is vitally important to measure specific heats, latent heats, and volume changes (including those produced by pressure) in order properly to interpret and utilize results of the measurements on silicates. Furthermore, past experience shows that it is not possible to make satisfactory progress in laboratory investigations involving certain synthetic minerals unless we have adequate means for the identification of products too finely crystalline for microscopic determination, and for this reason X-ray and electron diffraction techniques should be made available.

The second kind of investigation of prime importance and worthy of early implementation is the prospecting of the interior of the earth by "seismic" methods, using sufficient explosive to obtain clear records at the required distances. This is a large project, and it appears that it could be most effectively undertaken jointly with the Department of Terrestrial Magnetism and in cooperation with other interested agencies. The first objective would be to determine with high precision the wave velocities within the earth at depths in the range between, say, thirty and one hundred miles. Such measurements, in conjunction with adequate determinations of the elastic properties of typical rocks, would help to identify, in a chosen locality, the materials below and just above the major discontinuity that marks the lower surface of what is commonly called the earth's crust. The experiment would need to be repeated in other localities, including eventually the ocean basins; and in volcanic regions the work might well be coordinated with other kinds of prospecting and with chemical and other studies.

For the two classes of investigation that should form the Laboratory's main program, a theoretical treatment of certain problems is desirable. Such transformations as melting or change of crystalline form depend upon the forces between atoms and molecules. It is quite likely that rapid progress in our understanding of both the conditions of mineral formation and the state of the earth's interior would be facilitated by successful theoretical studies of intermolecular and interatomic forces in selected crystalline and liquid materials.

Group II. Other projects of great importance, some of which should probably be taken up by the Laboratory when the opportunity presents itself. In some instances, these investigations need further defining and delimitation, and in some instances they naturally grow out of the projects preferred for earliest attention.

There are several types of investigation logically belonging in the main program that should be high on a list of projects arranged in order of importance, and that are relegated to group II only because of the limitations imposed by the amount of space and facilities readily available at a laboratory of the size of the Geophysical Laboratory.

One of the important fields for experimentation is that of the production and control of ultra-high pressures. Among the possible applications of such techniques

are some of great interest and value to geophysics, such as determinations of volumes of solids at pressures far beyond the present experimental range, and the obtaining of further information on the effect of pressure on magnetism. This kind of research could profitably be undertaken in cooperation with the Department of Terrestrial Magnetism.

Studies on subjects such as the viscosities of liquids and the rates of crystal growth could also profitably be made. The latter might connect up with the determination of the conditions for production of large synthetic crystals of quartz and other minerals.

In this same category would be placed the study of vein formation and a comprehensive investigation of equilibrium relations in sulfide solutions for the purpose of obtaining basic information on solutions involving water, hydrogen sulfide, sulfuric acid, and metallic sulfides.

In the past, the Geophysical Laboratory has made definite contributions to volcanology, a branch of science that, in view of the information on the earth's interior that may be revealed by active volcanoes, deserves more attention than it has received from those interested in geology and geophysics. It will be worth while to formulate specific plans for further observations of volcanoes and the determination of subsurface structure in volcanic areas.

Group III. Projects of real interest in geophysics, but less closely related to the main project. Some of these might eventually be undertaken on a closed-project basis; but in general they might well be promoted, or encouraged, at other institutions.

Among the types of investigation that, although they are of vital concern to us because they help to attain the main objective, cannot (as it appears now) be undertaken by us in the near future, without diluting our efforts to an unprofitable extent, are: measurement of radium in rocks for the purpose of determining the generation of heat in the crust and of making further estimations of the age of the earth; measurement of temperature gradients in deep bore holes; measurement of thermal conductivity of rocks; ocean-bottom sampling, especially in the deepest parts of the ocean; studies on the plastic deformation of rocks with directed pressures superimposed on hydrostatic pressure; and various kinds of measurement relating directly to alteration and replacement.

For all these subjects, it would be advantageous to find means, in one way or another, to encourage universities, research institutions, and other organizations to carry out investigations related to the central program, with such assistance by the Geophysical Laboratory as the circumstances may justify. This is one phase of the cooperation mentioned below.

In addition to the specific projects that bear in an important way upon our central problem, there are many others with which it is not practical to concern ourselves at this time, because the projects would overload our facilities for even indirect attention. If deemed to be of sufficient general importance they will, sooner or later, be taken up elsewhere. It may be of interest to note a few samples of suggestions received from various sources and falling in this category: use of scale models to study intrusion, extrusion, joints, faults, shearing, flowage, doming, and other aspects of tectonophysics; investigation of colloidal phenomena pertaining to the formation in sediments of minerals such as glauconite and hematite; experiments bearing on the stability of roofs in batholiths, on the cause of shattering at batholithic contacts, and on the validity of the stoping hypothesis; experiments on what appears to be Nature's mode of extending dike fissures; and

investigations of the behavior of fine-grained rock aggregates in contact with various materials in the presence of water.

Cooperative Undertakings

It should be quite evident that the general problem is one of formidable complexity and that any existing group of investigators can be expected to cover properly no more than a small portion of the field. The staff of the Geophysical Laboratory can make their best contribution by pursuing actively a strictly limited number of lines of investigation and by cooperating with other individuals and groups on problems of mutual interest. As was stated above, two subjects, namely the "seismic" prospecting of the earth's interior and the study of the properties of materials under extreme pressure, seem especially suitable at this time for joint attention by the Department of Terrestrial Magnetism and the Geophysical Laboratory.

Other opportunities should be sought, both within the Institution and without, for the pooling of interests and efforts. It may be found that there are facilities in various academic and commercial organizations that for a limited period could be brought to bear on important projects in the program of experimental petrology, to the advantage of all concerned. The Institution, by its very nature, is in a peculiarly favorable position to enlist the cooperation of other agencies on a mutual-benefit basis. Furthermore, it will often be practicable to engage specially qualified men on a fellowship basis, and to have the benefit of their services and their points of view during the tenure of their appointment, after which in a new environment they may spread such new ideas and implant such specialized techniques as they may have absorbed. In this way, our efforts can be made more effective in solving the problems we attack, and the results of our investigations will perhaps have an earlier and wider utilization.

We therefore consider that, as an integral part of the proposed program for research at the Geophysical Laboratory, we should, in the future, take more advantage of all opportunities for close and frequent contact with investigators having interests similar to ours, and we should more earnestly seek to augment the Laboratory's own efforts by encouraging, supporting, and working with chosen allies.

General Problems in Earth Sciences That Will Be Illuminated by the Proposed Investigations

It is reasonable to inquire as to what would be the end result of the program as broadly outlined here—what great or small problems in geology and general geophysics it would illuminate. The first answer that might be made would refer back to the 1902 Report of the Institution's Advisory Committee on Geophysics. That report, which may be said to have led eventually to the establishment by the Institution of a department devoted to some aspects of geophysics, and thus to have constituted the first step in launching the Geophysical Laboratory on a thirty-year program of researches, enumerated a series of problems of which some have been satisfyingly if not completely solved and some have scarcely been considered. As was stated in Year Book No. 3, the originally suggested program, involving a wide range of subjects, was narrowed down and focused on an investigation of melting phenomena with emphasis on "the simultaneous application of pressure and temperature to the rock-forming minerals in the presence of water." This was to be the preferred line of attack on the great problems to which attention had been directed

Therefore, we might answer the inquiry by saying that the present purpose of the Laboratory does not differ in essence from what it was in the beginning; that our intention is to complete, as far as may be practicable, the task to which the Laboratory dedicated itself in the early days of its existence; and that the problems in earth science on which the results will shed light are to be found among those enumerated by the Advisory Committee of 1902.

But it can be urged that after many years of work in the field we should be required to plan more specifically than was possible at the outset and that we should be prepared to answer such questions as: What form have the great unsolved problems of the earth's interior now taken? What important gaps in the theory of the evolution of igneous rocks remain? How may the proposed experimental and theoretical investigation aid in the solution of these problems, and to what extent?

Very briefly, it may be said that the proposed investigations should help to solve such broad fundamental problems as the source of deep-focus earthquakes, the nature of the forces giving rise to mountain building, the source of the earth's magnetism, the reason for the existence of volcanic regions, the genetic relationships of rocks, and the composition and physical state of the earth's interior.

As for the application to the problems dealing with the origin of rocks and to other problems that are uppermost in the minds of petrologists, the following are some of the more important considerations. The "wet" silicate program would tell us the conditions under which hornblende (amphiboles) and micas are formed. A study of melts containing volatile compounds is important also because in general these compounds increase fluidity, lower the temperature of crystallization, alter the course of crystallization, and may even produce different minerals at various stages in the crystallization sequence. There exists little real evidence as to the original water content of rock magmas. Data on the amount of water that may be dissolved by molten silicate mixtures at a range of temperatures and pressures will apply to a variety of important geologic problems. Furthermore, a study of the role of water in magmatic processes should throw light on "granitization," which some geologists consider to be a major problem of igneous and metamorphic geology. The study of wet silicates would naturally grade into studies of highly aqueous residues which would bear on pegmatite and vein formation; and the latter would include much-needed investigations on the formation of sulfide minerals. Furthermore, laboratory studies on silicate and on sulfide mixtures, with volatile components, would contribute information useful in the interpretation of volcanic phenomena. Finally, in the opinion of one of the most eminent American geologists, thermal measurements, of the kinds described in preceding sections, are of prime importance because the amount, origin, and distribution of the earth's internal heat control the ultimate solution of all geologic problems.

Integration of Efforts

It is essential that the broad problems of earth history be broken down into a series of simpler problems, the solution of which contributes to the solution of the major problem. Unless the variables are isolated one by one and their individual and collective importance is evaluated by experimentation, progress will inevitably be slow and unsatisfactory. Furthermore, the investigations require the best efforts of physicists, chemists, and geologists working in very close collaboration.

Physicists and chemists, as a rule, have

little knowledge of geology, and although the geological members of the staff would in most cases need to have had good training in laboratory experimentation, it cannot be expected that they would have a close acquaintance with many fields of physics and chemistry. On taking up a new phase of the work, it will be profitable for the investigator to keep in mind the broad objective and at frequent intervals to exchange ideas with his colleagues. Frequent discussions and the ironing-out of divergent points of view are particularly important among those working on the various parts of a program aimed at improving our knowledge of the earth. It is also important that such a program should retain a certain amount of fluidity and that it should be reviewed now and then for the purpose of improving its unification by abandoning unprofitable lines of attack and devising suitable new ones.

In this connection, it may be worth while to emphasize the desirability of encouraging staff members, including physicists and chemists as well as petrologists, to take part occasionally in geological field expeditions. For the experimental petrologist, this is important because he needs to renew his interest in field problems and to have an opportunity for evaluating by personal observations the applicability of mechanisms suggested by laboratory experimentation. For the chemist and the physicist working on fundamental problems in experimental geology, field trips under competent guidance are of equal or even greater importance. One cannot expect to inspire an investigator with an interest in the ultimate goal, which is a better understanding of the earth's chemical and physical state, unless the investigator is now and then brought close to the earth by being given a firsthand view of selected features. Laboratory workers in the field of earth sciences tend to become dogmatic; but after a visit to Nature's laboratory, they more readily appreciate the realities of geology, and because of a better grasp of the problems and their complexity can more effectively plan the experiments.

It has been the practice at the Laboratory in the past to encourage staff members to take part in suitable field trips or expeditions when favorable opportunities arose. These at times took the form of joining in with geological parties engaged in studies of certain areas, for the mutual benefit that might accrue. To the extent that suitable arrangements can be made, this practice should be continued in the future.

Résumé

Originally the Geophysical Laboratory undertook to determine by quantitative methods the conditions under which the various igneous rocks could have been formed and the possible interreactions of such rocks under varying conditions of temperature and pressure. During somewhat more than thirty years of activity in this field, the Laboratory has produced a variety of significant results on the melting relations of rocks and conclusions as to their origin. Furthermore, as may be seen from an inspection of the more than one thousand technical and scientific publications of the Laboratory, it gradually branched out into a variety of problems more or less directly related to the main one. After a review of past work by the staff and a careful consideration of the most suitable problems for the Laboratory to attack in the future, and after seeking advice from a number of leading geologists and geophysicists, it appears that the Laboratory's domain should not be drastically changed from what it has been in the past, but that the program should be narrowed down and refocused on a well co-

ordinated and relatively small group of problems. Our field in the past may be described as experimental geology, and in all probability the Laboratory will make its best contribution to science in the future by remaining essentially in that same field —at least in the sense that we agree to consider geology a three-dimensional domain and not to confine our interests merely to the surface layers of the earth.

It is therefore proposed, first, that the general objective of the Geophysical Laboratory be to investigate *the composition and nature of the earth as a whole,* and, by the application of physics, chemistry, and mathematics to specific problems involving the genesis of igneous rocks, the changes that take place in them, and the constitution of the earth, including its interior, to obtain a better understanding of *the processes by which, during geologic ages, it reached its present state.*

Consistently with this general purpose, we suggest a program the framework of which consists of a few lines of attack on the main objectives. If, from the long list of specific problems in the large field, we select those that best meet the criteria of having fundamental importance, of collectively forming a compact and workable program, and of being the type that can most effectively be carried out by, or in some cases sponsored by, an organization with the peculiar advantages of this Institution, we note that the selected specific problems may advantageously be divided into three groups as follows:

In the first group we place those projects that should be taken up now by the Geophysical Laboratory. A major part of its effort would be directed toward the investigation of the melting and solubility relations of silicates, and later other compounds, in the presence of water and other volatile components under pressure. As an integral part of this phase of the program, measurements of thermal quantities and volume changes would be carried out, some pertinent theoretical studies would be made, and necessary techniques for the experimentation and for the identification of products would be applied. Another project for the near future would consist in prospecting the interior of the earth by seismic methods, presumably in cooperation with the Department of Terrestrial Magnetism. Furthermore, sufficient "slack" in the program would be allowed for a limited number of exploratory investigations on especially promising subjects. It will be readily understood that among the matters to which a high priority must be attached are the preparation for publication of the results of investigations completed but not written up before the war, and the "salvaging" of some other previous efforts by completing certain projects regardless of their position in our present list, if their intrinsic importance justifies spending a limited amount of time on them.

Next we have a group of projects, also of great importance, some of which should probably be taken up by the Laboratory at as early a date as it becomes practicable to do so, consistently with available facilities, staff, and the completion of other problems. In this group would be investigation of the development of methods for obtaining and using ultra-high pressures, investigation of sulfide solutions in relation to ore deposition, measurements on the viscosities of liquids, experimentation on the growth of crystals, and field studies of active volcanoes by the application of chemical and physical methods.

In the third group we place problems that, although of real interest in geophysics, are less closely related to the main project. Some of these might eventually be taken up by the Laboratory on a short-term basis, but most of them are of such

a nature that they could presumably be carried out advantageously by other organizations, with the Institution remaining in close contact with the work. Examples of this class are radioactivity of rocks, temperature gradients in the earth, thermal conductivity, ocean-bottom sampling, studies on the deformation of rocks, and systematic determinations of crystal structure by X-ray and electron diffraction methods.

It has been pointed out that the complexity of the broad problem is such that it will be particularly desirable to take advantage of opportunities for cooperation with other groups, both within and without the Institution. Because the Laboratory's own work, as carried out in the past and as proposed in the future, is a mixture of chemistry, physics, and geology, it is necessary for the staff to consist of specialists in each of these fields and to arrange for an effective integration of their efforts.

We believe that the family of preferred investigations outlined in this report are the ones best suited to the Geophysical Laboratory; that, although difficult, they can be carried out successfully; that the solution of the specific problems will advance materially our knowledge of the earth as a whole; and that the results of such investigations, together with the conclusions to be drawn from them, might well be sufficiently fundamental to influence the thinking of those who ponder the mysteries of earth sciences.

During the year two articles were prepared for publication.

SUMMARY OF PUBLISHED WORK

(1085) Temperature measurements at Parícutin Volcano. E. G. Zies. Trans. Amer. Geophys. Union, vol. 27, pp. 178–180 (1946).

The temperature of the Aguan flow of basaltic lava which issued during December 1944 from the volcano Parícutin in Mexico was estimated to be 1200° C and thus lies in the same range as that of other basaltic lavas. This value was obtained by means of an adequately protected chromel-alumel thermocouple connected to a portable potentiometer. Evidence is presented which shows that the gases emitted at this temperature did not burn when they came into contact with air. This indicates that if combustible gases are present their percentage concentration must be small. Measurements were also made of the temperature of the gases escaping from the fumaroles located on the older Zapichu flow; a maximum of 640° C was recorded.

(1086) Phase relations in the system sulfur—silver and the transitions in silver sulfide. F. C. Kracek. Trans. Amer. Geophys. Union, vol. 27, pp. 364–374 (1946).

This paper presents the melting relations for the entire system sulfur—silver, together with a study of the transition behavior of silver sulfide. Silver sulfide melts at 838 ± 2° C and undergoes two transitions in the solid state, each of which occurs at variable temperatures over a limited range of composition. The mean temperatures for the lower transition (Ag_2S III = Ag_2S II) are 177.8° C in sulfur-rich and 176.3° C in silver-rich preparations; for the upper transition (Ag_2S II = Ag_2S I) they are, respectively, 622° C and 586° C. A discussion of a possible mechanism for the incorporation of a limited excess of sulfur or silver into the lattice is given, based on the semiconducting properties of the substance and lattice disorder.

The melts of silver sulfide form two liquid layers in sulfur-rich melts at 740° C, and in silver-rich melts at 906° C. The two liquid layers at 740° C have the composition 0.035 and 64.0 atomic per cent Ag, and those at 906° C, 68.9 and 94.2 atomic per cent Ag, respectively. There are two eutectics in the system: one, of silver sulfide and sulfur at 119.3° C, containing less than 0.01 atomic per

cent Ag; the other, of silver sulfide and silver at 804° C, containing 68.0 atomic per cent Ag. As will be seen from these results, silver sulfide has a very low solubility in molten sulfur at temperatures below 740° C.

(1087) Annual Report for 1945-1946.

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DEPARTMENT OF TERRESTRIAL MAGNETISM

Washington, District of Columbia

JOHN A. FLEMING, *Director*

SUMMARY

The surrender of Germany in 1945 and of Japan early in the report-year (July 1, 1945, to June 30, 1946) brought to an end the long struggle since 1939, which has diverted almost all scientific investigators and organizations into paths bearing on the grim business of war. This Department's personnel and program, as briefly summarized below, have assisted our own government by taking over the development of many problems whose solutions have involved fields of its research and world-wide data it has acquired since 1904. Happily most of our developments for defense have involved the results not only of old lines of approach to theoretical and experimental studies, but also of new lines in our fields of research. Naturally the work required to complete contractual commitments—some undertaken only a few months before cessation of hostilities—with various war agencies, although in large measure done before June 30, 1946, will make some demands on administrative resources and scientific personnel of the Department for the remaining months of the calendar year 1946. It is also inevitable that more time will be needed for full consideration and decision regarding the reconversion from wartime to a normal peacetime program of research; memoranda toward solution of this problem have been under way since November 1945 (see pp. 38–39). The long period of considerable interruption in the Department's normal program furnishes opportunity to assess the desirability of continuing or abandoning certain activities maintained during the years before 1942 and of pursuing new objectives suggested by an examination of the status of science at the end of the war.

All members of the scientific staff were requested, therefore, to prepare memoranda on background of investigations completed or in progress, interrelations of programs of our sections and of those of other research organizations, and recommendations for future studies, facilities, and extent of personnel. Significant and thoughtful constructive and critical statements on reorganization of activities and related research were submitted in the latter part of 1945 and were thoroughly discussed in several staff-conferences. The subjects so considered were as follows: (*a*) geomagnetism by Vestine, McNish, Rooney, Forbush, Scott, Parkinson, and Ledig; (*b*) geoelectricity by Gish, Wait, Torreson, Rooney, and Sherman; (*c*) ionosphere by Berkner, Wells, and Seaton; (*d*) laboratory and nuclear physics by Tuve, Hafstad, Roberts, Berkner, Abelson, Cowie, and Heydenburg; (*e*) automatic calculation by machine in geophysical analyses and reductions by McNish, Vestine, Forbush, and Shapley. Brief extracts only from each of these statements are included under the appropriate items in the review of the year's work below. The many valuable suggestions of these complete and voluminous memoranda must be carefully considered before decision as to the extent to which, in the coming years,

programs may be profitably pursued, taking account of available resources of personnel, equipment, and funds, and possibility of exchange of scholars and of cooperation with other organizations active in the various fields.

Professor Sydney Chapman (Queen's College, Oxford), long expert counselor and contributor in the Department's operations and a pre-eminent world authority in geophysical research, who reviewed a complete file of the memoranda, comments as follows (January 1946):

I found the file extremely interesting, full of good ideas and plans, and showing clearly what an able, alert, and well-assorted staff DTM has gathered together. . . .

As regards nuclear and biophysics and DTM, the former is now "well dug in" and has a highly successful record in the Department. There is obviously a great field of highly valuable work in front of this Section; but there is a danger of this work gradually ousting the geophysical side. That, I think, would be lamentable, because the nuclear and biophysics is in no danger of neglect from universities and their research institutes, but the geophysical side of DTM needs greater resources and longer continuance of a stable policy than most universities could or would devote to such a subject; if CIW allowed this work to languish, a situation (as regards geomagnetic and associated research) that DTM has largely rescued from chaos and neglect would slump badly once more, whereas what is needed is a big new advance. The field of work is one that demands a considerable group of research teams led by men of first-class scientific and technical gifts, whose problems would fully stretch their powers. I like the full-blooded defence of this field in the majority of the proposals—I think it thoroughly justified; in fact, the papers in many of the proposals seem to me to outline an inspiring program of technical studies so closely agreeing, except in relative detail or omission here and there, with what I would have proposed, that I feel it unnecessary to add anything to it in such a general letter as this.

There is, however, one considerable proposal in this field that I would like to make, namely, that DTM should prepare a draft plan (or perhaps more than one, as alternatives) of the organization that would be needed to put the world magnetic survey (mainly by air, and with its due complement of magnetic observatories) on a reasonably satisfactory and permanent footing. DTM is, I think, the organization best fitted by its own varied experience and knowledge to do this, though other candidates for the job might be the Coast and Geodetic Survey or our British Meteorological Office, whose comments on a DTM plan should in any case be very helpful. It seems to me clear that the world, for civil aviation and shipping, should have this job of magnetic survey done properly and regularly, and probably some UN organization (perhaps under UNESCO) is the only means of ensuring that. To bring the matter effectively before UN it is necessary to have a draft plan and tentative budget such as I suggest DTM should prepare; but I think DTM and CIW should not only make the plan, but also collect a committee of men with those talents and experience—in politics, government, and diplomacy—needed to bring the plan effectively before UN so that the plan should be likely to be adopted and put into execution. That would indeed be a grand achievement, and should result in a lightening of some of the burdens that DTM has perforce undertaken in the past—land and ocean magnetic surveys and observatory work—freeing energies for work in other directions. Certainly such a UN organization if set up would not leave DTM free from a job; the continued existence of a "free" research institution alongside the international organization with its fixed tasks would be of great importance in providing independent critical assessment of the organization's work, and continual aid by the development of improved methods and instruments. And in any case pure geomagnetic research (in its broadest sense, as outlined in three of the proposals above referred to) would remain

the field mainly of DTM and individual workers elsewhere, as now.

A summary of war activities during the report-year is given later (see pp. 44–48) as part of a general statement for the period 1940–1946.

Review of Year's Activities

Geomagnetic investigations. Isoporic charts based on secular-change results at about 2000 stations were completed for epochs 1912.5, 1922.5, 1932.5, and 1942.5 for seven geomagnetic elements at ground level and for three elements throughout the atmosphere up to 5000 km. Included also were charts for the potential and vertical gradients of secular change at ground level.

Main-field isomagnetic world charts for declination (D), horizontal intensity (H), and vertical intensity (Z) based on results at about 10,000 stations since 1905, in 17 sections each, were completed for epoch 1945.0. Corresponding charts for the northward (X), eastward (Y), and total (F) components of intensity and for inclination (I) are roughed out preparatory to final inking.

Spherical harmonic analyses of the secular-change charts at four epochs were completed. It is inferred that secular change is likely to originate mainly in the mantle of the Earth in the presence of a region of extremely high electric conductivity. Spherical harmonic analyses of the main-field charts and of various geomagnetic variations are under way.

Attention has been given to the problem of magnetic surveys by air, in which it is expected that sufficient accuracy may be attained to make the data important for scientific investigation of such problems in geomagnetism as the separation of the internal and external fields of the Earth and the determination of the existence or nonexistence of the so-called nonpotential portion of the field. Though it cannot be expected that aerial observations will be as precise as ground observations, the superior coverage obtained from the air will make data so obtained more significant for analytical purposes than the present ground observations. Observing at isolated points on the Earth's surface, one is continually confronted with the "sampling problem," that is, whether or not the data obtained from a given region adequately represent the magnetic field over that region; also the ground observer is often unable to conduct observations in certain places. These conditions are present particularly over oceanic and polar regions.

Investigations have been conducted to improve the reliability of prediction of magnetic storms on the basis of their recurrence-tendencies, employing the principle of multiple correlation, a method which has recently been generalized by the work of Wiener. Sufficient improvement in results is obtained to make the method worth while.

Methods for analyzing measurements of total intensity obtained with airborne magnetometers in which the field of anomalies being measured is resolved into a vector-field by the total intensity of the undisturbed field have been developed and experimentally applied.

The third biennial award of the Charles Chree Medal and Prize of the Physical Society of London, "awarded for distinguished research in Terrestrial Magnetism, Atmospheric Electricity, and related subjects, branches of knowledge in which Charles Chree, Sc.D., F.R.S., Past President of the Society, was especially interested," was made by the Society's Council on March 16, 1945, to the Director "in recognition of his work in Geophysics." The medal and prize with certificate dated November 16, 1945, were presented in

person at the Society's meeting in London on December 6, 1945. In acknowledging this recognition of the value of investigations which he and his colleagues at the Department of Terrestrial Magnetism had found it possible to make during a period of more than four decades with the support of the Carnegie Institution of Washington, on behalf of himself and colleagues the Director presented an address entitled "Geomagnetic secular variations and surveys." The abstract of the address summarizes in more general terms the past and recent work above noted, as follows:

The secular variations of the Earth's field call for frequent determinations of the geomagnetic elements at many selected stations on land and at sea. So far, general world magnetic surveys have of necessity been restricted to the surface of the Earth. Previous surveys, including those of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, have led to great improvement in our knowledge of the distribution of the field, especially during the past few decades. During the war, much attention has been devoted to the study and analysis of data well distributed over the Earth's entire surface at more than 10,000 stations. These have resulted, for the first time, in the preparation of accurate isoporic charts, that is, charts of equal annual rate of change for magnetic declination, inclination, and the horizontal, vertical, eastward, northward, and total components of the field for the four epochs at intervals of ten years from 1912.5. The motions of the maximum and minimum isoporic foci during these four epochs indicate the complexity of the secular changes and interpretations.

Isomagnetic charts based upon surface observations must always be limited, so far as faithful depiction of the field is concerned, because of the impracticability of obtaining observations at an infinite number of stations and of deductions for both the regular and irregular changes in the field. Progress in instrumentation during the war on the applications of the geomagnetic field of the Earth have produced improvements which make feasible the early realization of magnetic surveys by airplanes at several different levels proposed by Professor Sydney Chapman in the first Charles Chree Medal Address. Some of the potentialities, possibilities, and needs for intense national and international coordination in magnetic surveys by plane are reviewed.

Among the suggestions for geomagnetism may be noted the following: "Geomagnetic researches, including associated researches in cosmic rays and earth-currents, conform to the indicated purpose of the Department." The main problems of geomagnetism "are as follows: (1) main field—(*a*) cause, origin, and maintenance, (*b*) properties of magnetic field of large bodies, (*c*) effect of main field on ionosphere; (2) secular variation—(*a*) cause, origin, and maintenance, (*b*) secular variation in past history of Earth, (*c*) relation to main field; (3) magnetic storms—(*a*) mechanism of magnetic storms, (*b*) electric current-systems responsible, (*c*) solar causes of magnetic storms, (*d*) prediction of magnetic storms, (*e*) relations to aurora, cosmic rays, and ionosphere; (4) solar and lunar daily variations—(*a*) relation to ultraviolet radiation of Sun, (*b*) electric conductivity of atmospheric region in which electric currents responsible flow, (*c*) relation to ionospheric phenomena; (5) short-period geomagnetic fluctuations —(*a*) mechanism responsible, (*b*) relation to solar and allied phenomena; (6) currents induced in Earth by geomagnetic variations—(*a*) morphology of earth-currents, (*b*) inferences respecting Earth's interior, (*c*) relation to magnetic variations. The previous policy of emphasis upon observational and descriptive aspects of geomagnetism should now be reorientated toward greatly increased emphasis upon interpretations of material on hand. In

these researches it is now possible to make use of automatic machines such as those of the International Business Machines Corporation for simple processes, and the more erudite devices for more difficult analytical problems are highly recommended to expedite all Department work of this type."

Cosmic relations. Provision for the maintenance and operation of cosmic-ray meters at five widely distributed locations, as noted in last year's report (Year Book No. 44, p. 22), was continued. Delay in reconversion to a peacetime program prevented any statistical investigations of available cosmic-ray data. The Institution's Committee on Coordination of Cosmic-Ray Investigations was disbanded June 30, 1946, and its work was transferred to the Department (see pp. 91 ff.).

The Department continued to act until June 30, 1946, as a clearing house for sunspot-data obtained by many observers of the American Association of Variable Star Observers and to receive and compile indices of geomagnetic activity from magnetic observatories. It is hoped that these responsibilities may once more be assumed by the International Unions of Astronomy and of Geodesy and Geophysics.

Terrestrial electricity. A reconnaissance study was made of lightning and associated electric phenomena at the Parícutin Volcano in Mexico to determine whether electrical studies under the unique conditions there would advance understanding of generation of electricity in thunderstorms. It was found that changes in the electric field associated with the volcano-cloud were much smaller than those in thunderstorms.

Continuing tests and discussion on data regarding pollution of the Earth's lower atmosphere demonstrated that pollution is gradually accumulating over the ocean near industrial land areas, near principal ocean trade-routes, and also over the more isolated regions of the ocean; this accumulation has increased pollution 100 per cent or more in 15 years and raises a question as to increase in the amount of foreign gases in the air.

Study on the rate of atmospheric ionization revealed (*a*) diminution when the soil is wet as compared with that when soil is dry, and (*b*) definite annual and diurnal variations.

"In the future investigations of atmospheric electricity at the Department it is recommended that attention be given chiefly to problems which involve much less in the way of amassing data and burdensome statistical analyses than has been the case in the past.

"Investigations of this character which are deemed most appropriate and important fall in the three following categories: (*a*) electrical phenomena and properties of the higher troposphere and of the stratosphere; (*b*) testing specific hypotheses regarding the maintenance of the Earth's negative charge; (*c*) testing specific hypotheses regarding the generation of the electricity in storms."

Ionosphere. By means of a new technique for recording phenomena in the upper layers of the Earth's atmosphere (the ionosphere), it was found, for the first time, that during magnetic storms—intervals when the ionosphere undergoes marked fluctuations which result in the fading or even the disappearance of radio signals—rapidly moving clouds of charged, or ionized, matter rush to the ionosphere, moving in from long to short range and out again at intervals of a few minutes. The clouds are of fundamental significance in their influence on radio transmission, and travel at a speed of about a mile per second. The new photographic panoramic ionospheric recorders developed at the Kensington Ionospheric Laboratory permit obtaining individual photographs of iono-

spheric activity at short intervals of 5 to 30 seconds; thus it is now possible by projection of the film-records as a motion picture to have visual presentation of the results, making for easier interpretation and study and broad applications in research and education.

A review of the relation of ionospheric research to the purpose of the Department, of the results already accomplished, and of the present status of the theoretical and experimental developments readily reveals many problems remaining to be solved with particular reference to fundamental progress within the scope of the Department's facilities. These problems may be listed in four general categories, namely, (1) continuous recording and observation, (2) fundamental analyses, (3) basic experiments, (4) specific engineering and prediction services. Programs of particular interest to the Department in future lie particularly in (2) and (3), and are suggested "with the following criteria in view: (*a*) They must be of fundamental importance to the science as a whole; (*b*) they should endeavor to avoid duplication of the work of others; (*c*) they should supplement the work of others in the Department; (*d*) they must be within the limit of material resources which can reasonably be made available; (*e*) they should fit other geophysical programs of the Department to permit the maximum of organized research on geophysical problems of general interest without completely subordinating the importance of individual researches; (*f*) they should visualize definite answers within reasonable time-limits, with at least a sprinkling of experiments which lead to a definite conclusion in not more than a few months; (*g*) they should be sufficiently flexible to provide facilities to follow through quickly on a new or spectacular discovery."

The suggested objectives are "fundamental, experimental, analytical, and theoretical investigations of: (*a*) the ionized regions of the upper atmosphere and of the space beyond; (*b*) the sources of this ionization; (*c*) the effects of this ionization; (*d*) related geophysical or extraterrestrial processes whose investigation is made possible by the presence of these ionized regions, or by the methods and techniques developed for their investigation; (*e*) the related morphology of the atmosphere."

Nuclear physics. The 1,000,000-volt electrostatic generator was reconditioned. Preliminary investigations were made on the angular distribution of the protons from the reaction $O^{16}(d,p)$. Progress is being made on revision of the electrostatic pressure-generator and tube to improve performance and reliability.

The 60-inch cyclotron was operated satisfactorily throughout the year, especially for bombardments for application to biophysical research. There was also produced one large sample of beryllium as a by-product providing a source of Be^{10}, the radioactivity of which presents problems as to the theory of the structure of light nuclei and that of beta decay.

The outstanding comment in the memorandum on the laboratory program is recognition of the scientific importance of past and current laboratory progress in nuclear physics and biophysics with the reservation that a more general program in laboratory physics is a vital part of any over-all program. The relations of such a program to the highly developed special interests "may roughly be classified as (*a*) systematics and relations of terrestrial magnetism and electricity, (*b*) experimental geophysics (including ionosphere), (*c*) laboratory physics. . . . The most outstanding and immediate need is for a Section on Theoretical Physics."

Observatory- and field-work. The com-

plete geomagnetic, atmospheric-electric, ionospheric, seismic, and meteorological programs were maintained at the Watheroo, Huancayo, and College magnetic observatories. Special studies relating to geomagnetic, atmospheric-electric, and ionospheric problems were made by the staffs at each observatory. The atmospheric-electric program in cooperation with the United States Coast and Geodetic Survey at its Tucson Magnetic Observatory was continued. We cooperated, through loan of instruments and otherwise, with eight observatories abroad.

Maintenance of International Magnetic Standards at the Cheltenham Magnetic Observatory of the United States Coast and Geodetic Survey was effected through the Division of Geomagnetism and Seismology of the Survey.

Though no field-work other than that at the observatories could be undertaken, it was possible to assist various governments, through loans of magnetic instruments, in undertaking new magnetic surveys and obtaining repeat-observations at established stations.

In view of the desideratum that the Department concentrate increasingly on theoretical matters and discussions of its accumulated geophysical data, considerable progress was made toward the transfer of the Watheroo and Huancayo magnetic observatories to agencies capable of maintaining the programs at the high standards set since they were established in 1919 and 1922. To this end preliminary arrangements have already been effected as regards the transfer of site, buildings, and equipment at Watheroo to the technical and administrative control and operation of the Australian Bureau of Mineral Resources, Geology, and Geophysics. That Bureau has now been established on a permanent basis by the Australian government and has been charged with the responsibility for the magnetic survey of Australia. The Bureau has already taken over the Toolangi Observatory, near Melbourne. It will be recalled that we have cooperated for many years with the Aerial, Geological, and Geophysical Survey, now absorbed in the Bureau, in magnetic observations in Australia. It is contemplated that the transfer will be concluded on July 1, 1947.

Miscellaneous. One suggestion, many times emphasized in the memoranda submitted on organization of our activities, relates to arrangements for exchange of scholars and graduate students qualified in geophysics. This has been carried on for many years by extending the privilege to such men of being guest-investigators, fellows, and research associates of the Department at Washington. During the report-year arrangements were concluded with the Institut de Physique du Globe of France, the University College of Dublin, Ireland, the Academia Sinica of China, and the Research Council of India for their representation by graduate students who will pursue geophysical research and training at the Department during the coming report-year. The Department, through its already established widespread connections and prestige in foreign lands resulting from its geophysical activities, is well suited for such international cooperation.

In 1946 the *Journal of Terrestrial Magnetism and Atmospheric Electricity* began its fifty-first annual volume. Many of the original papers of members of the staff were published, as heretofore, in that journal, which continued to be effective in the world-wide promotion and diffusion of geomagnetic and geoelectric knowledge and progress.

The continued services of two retired members of the staff, J. W. Green and W. F. Wallis, have been most useful in the emergency.

Henry Freeborn Johnston was retired June 30, 1946, because of ill health. He was active in the Department for over thirty years and took part in practically every branch of our program including the survey on land and sea and the work at observatories and at Washington. He did arduous field-work in South America and Africa and was for nearly six years Observer-in-Charge of the Watheroo Magnetic Observatory. From 1931 to 1946 he was Chief of the Section of Observatory-Work. His record is one of devotion and efficiency during his many years of scientific activity in the Department.

Fleming, who joined the staff as Chief Magnetician on May 1, 1904, was retired as Director on June 30, 1946. Tuve, a member of the staff since 1925, was appointed Director effective from July 1, 1946—a most suitable recognition of his proved outstanding ability as a scholarly investigator and of his splendid record in national-defense problems.

The appended bibliography lists papers published and special volumes on investigational results which have appeared during the report-year.

Review of War Applications, 1940–1946

It was possible to complete by or before June 30, 1946, all but three of the contracts undertaken by the Institution at the Department. These were (1) with the Signal Corps of the Army for establishing and operating ionospheric stations and developing apparatus, (2) with the Bureau of Ships of the Navy for compass improvements, and (3) with the United States Maritime Commission for work on compasses; all these will terminate within two to six months, and much of the time after June 30, 1946, is required for preparation of final reports, accounts, and inventories and disposal of property.

During the report-year the total number of progress-reports and final statements on results obtained under nonprofit cost contracts since 1940 was nearly 150. The contractual obligations, though not so heavy as in the preceding year, still took at least 80 per cent of the services of the available full-time and part-time regular staff of 64 in Washington and at the observatories. One hundred and sixty-four temporary employees (including physicists, engineers, mathematicians, computers, tabulating-machine operators, machinists, clerks, and guards) were necessary, and the total peak number of all persons engaged at the Department during the year was thus 228. Besides these, eleven of our regular and two of our temporary personnel continued on leave of absence either in the armed services or in governmental war agencies for part or all of the report-year; of these, four returned to duty at the Department in January, two in February, and two in May. In spite of the unrest of temporary personnel, hired for work on commitments to various war agencies, and their desire to secure permanent employment as soon as possible, these obligations have been essentially completed during the report-year. Many of the temporary personnel were again made available by various universities and individual organizations through generous granting of leaves of absence.

In view of the declassification of the developments at the Department on military problems, largely concerned with applications of geophysics, it is now appropriate to give a brief summary of operations for the years 1940 to 1946.

Most of the work at the Department was done under nonprofit, nonoverhead, cost contracts of the Institution with the Office of Scientific Research and Development and its National Defense Research Committee, various bureaus and laboratories of the departments of War, Navy,

Interior, and Agriculture, the Maritime Commission, the National Institute of Health, and, more recently, the Office of Research and Invention of the Navy Department. Through June 30, 1946 (at which time all contracts except three had been completed), the total of costs was $2,359,895.45. In addition, the Institution made available at the Department during 1940 to 1946, and without charge, all services of the regular scientific and administrative staff and use of all buildings and equipment there; a very conservative estimate of these contributions is well over $500,000. Besides these, again at its own expense, the Institution built an addition to the instrument-shop of its main laboratory and made many structural changes in its several buildings at the Department—all necessary because of contractual responsibilities.

The outstanding accomplishments are:

Navy Bureau of Ordnance. Compilation and preparation of world isomagnetic charts of seven components of the Earth's magnetic field (Vestine); establishment of the Kensington Magnetic Laboratory and experimental studies and tests (Ramsay, of the temporary staff) of magnetic mines and torpedoes (see p. 50); experimental magnetic and radio field-research (Seaton) at the College Observatory, Alaska; various magnetic investigations at Washington and in the field (McNish, Forbush, and E. A. Johnson). The earliest of these contracts, some of which were continuations of earlier contracts with the National Defense Research Committee, began in August 1940.

Navy Bureau of Ships. Work on improvement of ship's compasses (McNish) from April 1945 was largely completed, but the contract does not terminate until September 1946.

Navy Bureau of Supplies and Accounts. One contract called for investigations (Wells, Seaton, Fleming) of the ionosphere, wave-propagation, geophysics, and solar and cosmic relations at Washington, at College, and at many cooperating astronomical observatories, and was effective from July 1942 to June 1946; another concerned detection appliances by means of marine and land electric currents (Rooney), and was completed during March 1942 to December 1943; a third contract concerned isomagnetic charts (Vestine) during February to June 1942, and was superseded by a contract with the Bureau of Ordnance (see above).

Navy Bureau of Aeronautics. A contract concerning methods of aircraft navigation (McNish) was completed during the year ending in June 1946.

Navy Medical Center. Special radioactive isotopes by cyclotron bombardments, for biophysical investigations (Cowie), were supplied from June 1944 to June 1946 (for details of experimental work with these see previous annual reports of the Department and pp. 63–66).

Naval Research Laboratory. An especially valuable research on separation of uranium isotopes (Abelson) was completed during October 1940 to June 1941, in anticipation of the atomic-bomb development. During October 1944 to June 1945, special studies, design, and construction of atmospheric-electric recording equipment for use on airplanes and dirigibles were carried out (Rooney, Sherman).

Army Air Forces. Research and tests on applied methods of magnetic navigation for aircraft (McNish) were completed during the year ended May 1946.

Army Engineer Board. The successful design and construction of several magnetic devices for detecting surface and marine mines (McNish) was accomplished during November 1944 to July 1946, in continuation of a contract with the Office of Scientific Research and Development

beginning in August 1941. Altigraphs were designed, constructed, and tested (McNish) under a second contract during July 1945 to May 1946.

Army Signal Corps. The establishment and operation of widely scattered stations in the Atlantic and Pacific areas and development, construction, and tests of special recording and manual equipment for observations and discussions of ionospheric phenomena and their effects on radio-wave propagation (Wells, Fleming, Berkner, Seaton, and associates) have constituted a major war activity. This work was set up originally under a contract with the Office of Scientific Research and Development in July 1942, and was transferred to the Signal Corps auspices from February 1943; the present contract will terminate in December 1946, by which time authorized transfer of the ionospheric stations to the new Central Radio Propagation Laboratory will have been completed.

The Ionospheric Section, in the Allied program for improved knowledge of radio-wave-propagation conditions, installed, operated, and/or equipped fifteen ionospheric stations. These included: (*a*) an expanded schedule at the CIW Huancayo, Watheroo, and College magnetic observatories; (*b*) new stations with civilian personnel at Clyde (Baffin Island), Maui (Territory of Hawaii), Trinidad (British West Indies), Reykjavik (Iceland), Christmas Island (South Pacific), and Adak (Aleutian Islands, Alaska); (*c*) apparatus for new stations and training of civilian personnel for Leyte, Guam, Okinawa, Loshan (China), and one proposed (China —equipment now stored in Shanghai); (*d*) apparatus for St. Johns (Newfoundland) under Canadian auspices. A coordinated solar observing program was organized and maintained providing a basis for forecasting of ionospheric disturbances. A developmental program was conducted at the Kensington (Maryland) Ionospheric Laboratory to provide a new technique for ionospheric investigations which has broad applications in research and education. (For more details see pp. 59–60.)

Practically all the many classified reports on this activity under contracts with the Army, Navy, and Office of Scientific Research and Development, originally distributed to a limited list of authorized and interested parties, are now declassified. Already revision of the material where necessary is under way to prepare it in form suitable for publication in recognized technical journals.

The program set up by the Wave Propagation Committee has demonstrated in its results the urgent need of continuation in the postwar future in the general national interest, and it is apparent that continued obtaining of data from widespread stations is essential to military, commercial, and research postwar responsibilities and activities. Certainly the stations in Hawaii, in Alaska, on Christmas Island, on Trinidad, in the Aleutians, and in the Philippines should be placed on a permanent postwar basis and the ionospheric programs at Watheroo and Huancayo should be maintained for some years.

Army Service Forces (Supply Division, Camp Detrick). Radioactive materials, produced by the cyclotron (Cowie), were supplied in January 1945.

Bureau of Plant Industry (Agriculture). During January and August 1945, special radioactive isotopes were supplied (Cowie).

Geological Survey (Interior). During June to August 1946, an earth-current recorder was supplied, installed, and set in operation (Rooney) at Umnak Island, Alaska.

National Institute of Health. During August 1944 to June 1946, considerable quantities of radioactive elements and

compounds, for biophysical research, were supplied (Cowie).

Maritime Commission. The study of compass-behavior and improved compass-design (McNish, with Gingerich of the temporary staff) are the subjects of a year's contract, to terminate in August 1946.

Office of Scientific Research and Development (including National Defense Research Committee). Some of the most important contributions by the Department were completed on contracts with the Office of Scientific Research and Development and the National Defense Research Committee; others initiated by that Office and that Committee were so important as to be transferred later to military agencies for further development, as indicated above.

Outstanding among these were the development and tests proving practical feasibility of the radio proximity fuse (Tuve, Hafstad, Roberts), which were transferred by March 1944, with 100 staff members and equipment, for final arrangement of mass-production design and manufacturing to the Applied Physics Laboratory of Johns Hopkins University, especially inaugurated for that purpose. The development of the fuse began in August 1940, and was completed at the Department in March 1944. For some months prior to April 1943, the new Johns Hopkins group maintained operations at the Department pending completion of reconstruction of buildings to house it at Silver Spring.

Another development of prime importance was begun in April 1941 and completed in May 1945, on development of the odograph—an automatic route-drawing device, true in direction and scale, for use on tanks and on land, air, and ocean vehicles of all kinds—and the pedograph (a lightweight version of the odograph for use by individual soldiers), which involved extensive study of compensation and design of compasses and electronic circuits (McNish, with Dalke, Tuckerman, Agy, Duffin, and associates, of the temporary staff).

The development of magnetic mines (McNish) was carried on for the Office of Scientific Research and Development during three years ended in August 1944; this work and that on the odograph were later made parts of contracts with the Army Engineer Board.

As above indicated, the ionospheric investigations in Alaska, subsequent to the installations and the first year of operation at College, on funds provided by the Institution, were supported by contracts with the Office of Scientific Research and Development during March 1941 to June 1943, when transfer to Navy auspices was made. That Office also supported by two other contracts the original work done (Wells, Seaton) during August 1943 to June 1944 on the direction-finder program at College, and during July 1942 to November 1943 on aspects of solar and geomagnetic investigations (Wells) at Washington.

An important contribution was that relating to fission of uranium (Heydenburg) during September 1941 to September 1943.

Office of Research and Invention. The Department has kept closely in touch with the recently formed Office of Research and Invention of the Navy Department. It has attended many conferences of that Office and has furnished advice on many geophysical subjects—including Operation Crossroads—within the province of the Department's activities.

All the above contractual obligations, though interrupting the regular scientific program, have yielded by-products and improved techniques applicable not only to geomagnetic surveys and experiments, but also for mass reductions, analyses, and correlations by machine methods. Peacetime applications of these must serve both

the continuation of surface magnetic surveys and the initiation of aerial ones by our several governments, as well as interpretative investigations of the vast existing stock of data, and the potentially much greater stock which may be available in the near future. It is hoped that a long period of amity and cordial relations among all nations is now on the horizon, affording firm foundation for forwarding and coordinating future large activities in Earth physics.

INVESTIGATIONAL AND EXPERIMENTAL WORK

TERRESTRIAL MAGNETISM

The investigators and their assistants at Washington chiefly concerned with geomagnetic research included Miss Balsam, Chernosky (from February), Mrs. Crow (to February 14), Fleming, Forbush (from January), J. W. Green, Harradon, Hendrix, E. A. Johnson (from May), Miss Lange, McNish, Scott, Sherman, Vestine, Miss Walburn (from February 25), Wallis, and Wells, with Bernstein (to October 4), Miss Cooper, Dalke, Davids (to October 4), Duffin, Gingerich, Miss Laporte, Ramsay, Saltarelli (to September 15), Shapley, and Tuckerman (to October 15) of the temporary staff. In addition, some 30 temporary professional and associate workers were engaged for part of the year under terms of various cost-contracts having to do with geomagnetic applications to defense problems. The major effort of the staff was devoted to the near completion of contractual work concerned directly or indirectly with the war. During the year a major part of the classified reports, of large scientific value in geomagnetic research, was declassified, and some of the reports have already been published in technical journals.

Geomagnetic Investigations

Permanent field and isomagnetic charts. Spherical harmonic analyses of the north and east components of secular change were effected for each of the epochs 1912.5, 1922.5, 1932.5, and 1942.5 (Vestine). These were successfully used as an aid in constructing isoporic charts in vertical intensity which were less accurately defined from direct observation in many regions. This procedure also ensured that the isoporic charts for vertical intensity were mutually consistent with those for the horizontal component.

Isoporic charts were also derived for the potential and for the vertical gradients in the north, east, and vertical components of secular change. Isoporic charts for the latter components of field were likewise constructed for various levels (100, 200, 300, 500, 1000, and 5000 km) of the atmosphere.

Current-functions which could reproduce secular change were computed for spherical sheets concentric with the Earth at several vertical depths (0, 1000, 2000, and 3000 km beneath the Earth's surface) for the four epochs indicated above. Those for depth 3000 km are thought unreasonably complex. These complexities in current-pattern may arise in part from inaccuracies in the charts analyzed, but it seems more reasonable to interpret this result as indicating that secular change originates at depths not in excess of about 3000 km. The marked changes in pattern of current-flow from one decade to the next seem compatible only with the supposition of extremely high electric conductivity in the crystalline mantle at the level of current-flow rather than with great changes per decade in electromotive driving forces.

Similar analyses have been begun for the new charts of the Earth's main field, using automatic machines and punch-card techniques. A discussion of the foregoing work, along with similar analyses of various newly derived geomagnetic variations, was largely completed for publication in volumes of the "Researches of the Department of Terrestrial Magnetism."

The new isomagnetic world charts of the main field for the epoch 1945 were completed.

Development of Instruments for Aerial Surveys and Delineation of Magnetic Anomalies

Design and fabrication of test equipment (McNish, Steiner, and associates) for measurement of the geomagnetic field on an airplane, for two war contracts, were completed. Final tests had not been made at termination of the contracts. Because of the Department's basic interest in this project and its future significance in magnetic surveys, present plans call for continuation of this work at the Department in cooperation with the armed forces on a noncontractual basis.

This development focuses attention on new ways to interpret magnetic observations in connection with geological structure through aerial observation over regions of geomagnetic anomaly. The success of the magnetic airborne detector during the war and its release by the armed forces for research purposes afford a means of rapid and extensive magnetic surveying. The present form of this detector is capable of measuring only the total component of magnetic force, and it does not appear likely that any adaptation will permit measurement of vertical intensity or any other vectorial component of the force with any comparable degree of precision. Theoretically, no interpretation of total-force measurements is possible unless the direction of the force is also given; if the anomalies being measured are small with respect to the normal magnetic field of the Earth, however, a satisfactory approximation can be made in that the total magnetic field resolves the field of the anomaly into the component of the anomalous field which is parallel to the total-force vector, and this is the component that the detector measures. The direction of the normal field may be assumed constant over the area under investigation. If the field of the anomaly is only 100 gammas, the error introduced by this approximates to only one part in 250,000 in middle latitudes. Thus, the observed anomaly may be regarded as a vector-field in the direction of the total magnetic vector and as such is analytic. By the method of harmonic analysis, this vector-field is readily separable into its components in the vertical direction and in the horizontal direction toward magnetic north. Methods for handling data of this sort were developed.

Geomagnetic Disturbances and Cosmic Relations

Attention was given to improvement of methods for predicting magnetic storms on the basis of magnetic activity observed during previous solar rotations. Employing auto correlation coefficients of the magnetic character-figure, C, for the period 1890–1945, as obtained by Shapley, using punch-card calculating machines of International Business Machines (IBM) type, a different method for predicting magnetic disturbances was devised which makes use of the observed value of magnetic activity 1, 26, 27, 28, and 54 days before the day to be predicted. For a sample year on which a test was run, the correlation between predicted and observed values was 0.56 as compared with 0.32 using the 26-day recurrence tendency alone.

Correlative study of magnetic disturbance and microseismic activity at Huancayo by Chernosky was made using the seismograms for a two-year period. The maximum daily amplitudes of microseisms apparently show correlation with the magnetic character-figures, depending upon the time-lag introduced. Analyses thus far have been performed principally by the superposed-epoch method; correlation-coefficient analysis for some of the data is in progress on IBM equipment.

Because of needs of reconversion and delays in return of personnel from assignment to defense problems, only small progress was made (Forbush and Lange) in correlative research on cosmic-ray and geomagnetic phenomena. As will be noted under the annual report (pp. 95–96 of this volume) of the Committee on Coordination of Cosmic-Ray Investigations, this progress involved development of methods for computational improvements by calculating-machine techniques.

War Activities at Kensington Magnetic Laboratory, 1942–1946

One part of the nonprofit services contract with the Naval Ordnance Laboratory under which the isomagnetic-chart work (see p. 48) was done called for a group of facilities to provide that Laboratory with fundamental information regarding magnetic fields and measurements on magnetic mines and torpedoes. Following negotiations in July 1942, and after certain preliminary work, the first construction of four special buildings was provided in April 1943, and a fifth building was added in the following November. These laboratories, after it was determined that the site of the Department's Kensington Ionospheric Laboratory (KIL) was sufficiently uniform magnetically, were built on a part of that site and the group was called collectively the Kensington Magnetic Laboratory (KML). KML was used continuously until experimental work was discontinued on May 17, 1946, when the whole area of the Kensington installation was purchased for real-estate operations and became unavailable for use of the Institution after June 30, 1946. During May and June all the buildings of KML were either dismantled or cut in sections by the Department and transferred to the permanent site of the Naval Ordnance Laboratory at White Oak, Maryland; three of the buildings were later re-erected by the Naval Ordnance Laboratory at White Oak as a part of the permanent group of structures there.

The original five laboratories at KML were designated by names indicative of the facilities which they housed or the purpose for which they were used. (1) The Solenoid House provided shelter for two solenoids large enough in cross-section for measurements on ground mines and torpedoes and long enough to produce uniform magnetic fields. (2) The Helmholtz House contained square Helmholtz coils, 20 feet on edge and arranged to produce uniform magnetic fields in each of three perpendicular directions; it was used for magnetic-needle mines, large induction mines which could not be tested in the solenoids, and other devices such as those operating on total field for which simultaneous control of the three field-components was necessary. (3) The Gradhelm House contained a somewhat smaller three-dimensional Helmholtz and a gradhelm for producing uniform gradients used in testing gradient-actuated depth charges. (4) The Shop-and-Office housed office facilities, lead storage-batteries for supplying currents for the magnetic generators, and facilities for special measurements; during the last year of operation, a 40-foot solenoid was located in this building for measure-

ments on torpedoes. (5) The Phorage House provided a photographic darkroom, an immersion tank, a dropping pier, and space for storage and assembly of ordnance components.

From May 1943, all magnetic test-work done on magnetic mines, depth charges, torpedoes, and other underwater ordnance was conducted at KML. The staff which participated in this work consisted of (1) persons employed by the Department of Terrestrial Magnetism (DTM), (2) persons employed directly by the Naval Ordnance Laboratory, and (3) officers and enlisted men of the United States Naval Reserve. At first, the staff of 12 operated the facilities of the laboratory three shifts a day, seven days a week; before the end of the war, the total number on the staff was tripled, and greater efficiency and closer supervision were achieved by eliminating part of the night work. The satisfactory manner in which the magnetic characteristics of underwater ordnance were predicted was due largely to the careful and exhaustive tests carried out by this Laboratory in simulating the service conditions under which the weapons were employed.

Throughout its operation, KML performed services under the contract with large freedom from the encumbrances of red tape because of the appreciative understanding by DTM of the scientific objectives sought and the operating conditions necessary for achieving them. Thus KML could coordinate its work so closely with that of the Naval Ordnance Laboratory as to be in a practical sense an integral part of it. A large reason for the success of KML was the manner in which all relations between the two organizations were handled by Dr. George H. Shortley, who was Technical Representative of the Naval Ordnance Laboratory on the contract for most of its duration, and by Dr. B. P. Ramsey, who (generously granted leave of absence from the University of Kentucky) was in charge of operations for DTM.

Miscellaneous. Numerous progress-reports were prepared as the work of the Section developed. With the declassification of practically all contractual work, papers bearing on research of scientific value may be published, and this is already being done (see bibliography). Several memoranda particularly concerned with problems of reconversion and replacement of magnetic instruments and laboratories wholly or partially destroyed during the war were prepared.

TERRESTRIAL ELECTRICITY

War research in the Section of Terrestrial Electricity continued on a reduced scale from that of the three previous years. Gish continued as Chief of the Section, assisted by Rooney, Wait, and Sherman. Torreson completed editing, compiling, organizing, and preparing material and discussions relating to the atmospheric-electric work done at sea on the *Carnegie* in 1928 and 1929 (see p. 83). Rooney, having completed his war researches, compiled and discussed accumulated earth-current data.

Atmospheric Electricity

Lightning and associated electric phenomena at the Parícutin Volcano. On the invitation of the Committee of the American National Research Committee for the Study of Parícutin Volcano, Gish made a reconnaissance (July 8 to August 9, 1945) in the region of the volcano to determine

whether a program of electrical studies there seemed advisable and especially whether the understanding of generation of electricity in thunderstorms would be advanced by such studies. In a conference, following the trip, with representatives of the United States Weather Bureau it was agreed that the contemplated program under the unique conditions at Parícutin offered a good prospect of advancing understanding of the mechanism by which electricity is generated in storms. Some reasons for this conclusion are: (*a*) The occurrence of lightning at Parícutin, if present activity continues, is sufficiently frequent so that long periods of waiting for the occurrence of lightning would not be involved. (*b*) The displays of lightning are not too elaborate for satisfactory measurements and photographs. (*c*) The volcano is fairly approachable. (*d*) Volcano-clouds can be conveniently viewed from several angles. (*e*) The volcano is restricted in position and, in this and some of the foregoing respects, is much more favorable for observations than is a thunderstorm. (*f*) Some of the factors involved in the generation of electricity in the volcano-cloud doubtless differ from corresponding ones in the thunderstorm; such a circumstance is often turned to advantage in investigations of complex natural phenomena. It was decided, however, not to undertake the proposed program.

The lightning flashes observed in the volcano-cloud during Gish's visit and not attributable to general thunderstorm conditions were of two distinct types, namely: (*a*) flashes about 1000 feet long extending roughly parallel with the axis of the pillar of the volcano-cloud, usually between a point near the base of the pillar and the tip of the volcanic cone; and (*b*) flashes so short that many appeared as merely bright points of light. The flashes observed under (*b*) were chiefly in the upper half of the pillar and none was seen in the crown or the curtain of the volcano-cloud. No discharges of any kind issued from the roughly horizontal curtain cloud even though the streamers of falling ash were often conspicuous. A striking luminous effect around the border of the curtain was seen several times at night; this, however, was not a diffuse electrical discharge (St. Elmo's fire), but was definitely due to illumination from the lightning flashes of thunderstorms in progress beyond the horizon.

The changes of electric field associated with discharges in the volcano-cloud, observed with the aid of the electrometer, were much smaller than those accompanying the lightning flashes in thunderstorms. This is not surprising and doubtless depends upon the restricted dimensions of the volcano-cloud. The dimensions of the pillar, as well as the "activity" in it, appeared to be involved in some way in determining whether or not electrical separation would occur to the extent or in the manner necessary for discharge to occur. Separation of charge occurred at all times, as indicated by the response of the electrometer, but discharges were noted only in eruptions where the pillar had a cross-sectional diameter equal to, or greater than, three-fourths that of the crater (about 1000 feet).

The flashes, preponderantly of the small type with short flashes, occurred at an average rate of nearly one per minute for a period of two to four hours July 29, 1945. In general the relative rate at which the electric field was re-established, after a discharge in the volcano-cloud, was somewhat greater than in a thunder-cloud, but the contrast in this respect was not striking.

Gradual pollution of the Earth's lower atmosphere. The air about us is apparently

becoming increasingly polluted with foreign gases. These gases owe their origin to varied industrial operations and to erupted gases from volcanoes. The polluted atmosphere is not confined to the land areas, but extends far out to sea. The products of pollution are especially prevalent along the main trade-routes of the oceans. These conclusions (Wait) are based on results derived from measurements of condensation-nuclei during Cruise VII and of atmospheric electricity during all cruises of the *Carnegie*. The nuclei-content of the air over the ocean but near the land areas on which industrial activities are great was much higher than that at considerable distances from land. That near the main oceanic trade-routes likewise was relatively high—some ten times as great as that in more isolated localities. The nuclei-content of the air over the ocean in the volcanic region between Guam and the Japanese islands was nearly four times that near the main trade-routes or about forty times that over the more isolated oceanic areas.

The products of pollution appear to be gradually accumulating in the air over the ocean near industrial land areas, near the principal ocean trade-routes, and also over the more isolated regions of the ocean, as judged from the data on the electrical conductivity of the air on the various cruises of the *Carnegie;* for example, this pollution over the oceans during 1929 was apparently about double that during 1914. The added industrial activities of nations since 1929 in the preparation for war, and the release of vast quantities of foreign gases through the various war activities, give rise to speculation as to the extent to which such accumulation in the atmosphere has been augmented, particularly in the war zones themselves. Evidence from air-conductivity data at both Tucson (Arizona) and Watheroo (Western Australia) indicates that large increases in the amount of foreign gases in the air have occurred during the past few years even in remote regions of the Earth.

Rate of atmospheric ionization. An analysis (Wait) of results obtained in 1935 with a thin-walled ionization-chamber located in the free atmosphere in Washington, D. C., shows considerable diminution in the rate of ionization when the soil is wet as compared with that when the soil is dry, and also when the soil is covered with snow as compared with that when the ground is uncovered. These results are consistent with those obtained by various investigators on the rate of exhalation of radioactive gases from the soil, namely, a decrease in the rate when the soil is wet or covered with snow. Moisture in the soil capillaries acts to inhibit the escape of the radioactive gases from the soil, and a similar effect is brought about by a blanket of snow over the soil; thus the reduced rates of ionization with a thin-walled chamber can be accounted for. The analysis also reveals an annual variation in the rate of ionization, with a maximum in summer and a minimum in winter. There is also a diurnal variation, with the maximum during the early morning and a minimum during the evening. In winter both the maximum and the minimum are flat and indistinct, whereas in summer they are relatively sharp and pronounced. The diurnal variation is probably due to the combination of two factors, namely, the rate of exhalation and the rate of disappearance of the radioactive matter from the atmosphere, for each of which the variation is such as to produce a morning maximum and an evening minimum in the diurnal-variation curve representing the rate of ionization of the atmosphere.

Development of instruments and meth-

ods. In addition to reduction of atmospheric-electric records obtained at the observatories, considerable development of instruments was continued, including electronic equipment (*a*) to measure intense electric fields in the atmosphere and (*b*) for use with ionization-chambers.

In cooperation with the program of the Navy Department for Operation Crossroads, Sherman and Wait supervised the design, construction (by the Navy), and tests of six ionization-meters with electronic detecting systems.

Other instrumental work was concerned with tests and remodeling of some of the instruments used by Dr. V. F. Hess in his investigations of ionization at Fordham University.

The portable magnetograph of the type developed by Sherman and Vestine (see Year Book No. 43, p. 27) was used as control at a base-station near Point Barrow (Alaska) in the aerial survey of Navy oil reserves. Sherman effected the installation and adjustment there during July 1945.

Geoelectricity

Rooney kept current all reduction and tabulation of the earth-current records from Watheroo and Huancayo. He also made a study of all available earth-current data to determine the effect of length of lines used and the consistency and magnitude of recorded values. The deeper penetration effected by the use of long lines suggests that more uniform results should be obtained with installations of long lines. The results of the study were somewhat inconclusive, chiefly because of the scarcity of data from really long lines. There is some indication, however, that the magnitudes recorded on long lines such as those used at Berlin (120 km, 262 km) and Tucson (57 km, 90 km) are in better agreement than those found in comparing the results from stations using lines only 1 or 2 km long. Some of the differences which appear in the short-line records may be due to local structural variations, and such differences too should be expected to be lessened when longer lines are used.

THE IONOSPHERE AND ITS RELATIONS TO GEOMAGNETISM

Summary of War Activities, 1942–1946

Because of the reduction in security requirements it is now possible to present an outline of the wartime activities of the Ionospheric Section. The wartime demand on communications showed a dire need, in the early phases, for a detailed knowledge of ionospheric characteristics over the world in order to provide a sound scientific basis upon which to allocate frequencies for communications and to prepare forecasts of usable frequencies for all seasons of the year, times of day, and parts of the world. The Wave Propagation Committee (WPC) which was organized under the Joint Communications Board, Joint Chiefs of Staff, acted as the principal sponsoring agency. It included representatives from Army, Navy, National Bureau of Standards, and the Carnegie Institution of Washington (CIW).

The WPC, through its Army and Navy representatives, sponsored an expanded United States ionospheric program in coordination with other expanded plans by allied governments. The Interservice Radio Propagation Laboratory (IRPL) was established at the National Bureau of Standards (NBS) for the purpose of collecting radio-wave-propagation data and disseminating them to our armed forces. CIW assumed the task of implementing the expanded United States program in so far as additional overseas ionospheric stations were

involved. The nucleus of the plan of WPC for expanded ionospheric facilities was the allocation of four type-249 multifrequency ionospheric recorders from the British Admiralty. After the apparatus was received and tested at the Kensington Laboratory, it was modified so as to make it more suitable for field-station operation. After an extensive search for qualified personnel, a number of young engineers and scientists were employed to provide the basic staff for the new stations. The first four expeditions were sent to the following locations: (1) Clyde, Baffin Island, Northwest Territory (Canada); (2) Kihei, Maui, Territory of Hawaii; (3) Fort Read, Trinidad, British West Indies; and (4) Camp Waterloo, Reykjavik, Iceland.

The Hudson's Bay Company of Winnipeg, Manitoba, cooperated closely in the establishment of the Clyde Station. Without its assistance this would have been a much more difficult undertaking. Some equipment and supplies were packed at the Department and shipped to Montreal for loading aboard the icebreaker *Nascopie* of the Hudson's Bay Company; other building supplies, foodstuffs, fuel, and materials were loaded on the vessel at Churchill, Canada. Special arrangements were made to have the *Nascopie* stop on its northward voyage to discharge cargo at Clyde. On its southward voyage approximately two weeks later, in September 1943, it picked up the carpenters, who, by then, had practically completed the construction work. The ionospheric data from this station were of unusual significance because of its location inside the auroral zone. In general, the ionosphere was found to be much less disturbed than had been anticipated. The operation of the Clyde Station was taken over by the Canadian government in 1945, and the members of the Department's personnel were returned for other assignment.

The Maui Ionospheric Station was established early in 1944. Personnel and equipment were forwarded as a unit under United States Army travel orders. Following a survey by Wells, the site for the station was selected at an abandoned United States Navy installation near Kihei. A building was already available for conversion into an ionospheric laboratory and another building available for quarters for personnel. Arrangements were made for erection of vertical rhombic antennas in preparation for arrival of the field-party. Close cooperation and a great deal of material assistance were obtained from the Central Pacific Base Command at Fort Shafter (Oahu) and the Office of the Naval Commandant at Maui. The type-249 recorder is still in operation, and ionospheric data from this location continue to be of great interest because of the unusually high values of ionization recorded in the *F*-region. These values were found to be greatly in excess of any predicted ones, and early data from this station caused a considerable revision in forecasts of communication conditions in some Pacific areas.

The station at Fort Read, Trinidad, was also put into operation early in 1944. During a survey by Wells in 1943 it had been determined that an abandoned radio-range station was available at Fort Read and could be readily adapted for the ionospheric work. Arrangements were made with the Trinidad Sector and Base Command for the use of this building and for the erection of the required antenna system, which was essentially completed on arrival of the station's personnel. The ionospheric apparatus at Fort Read deteriorated rapidly because of the high humidity. Steps were taken to air-condition the laboratory, but the 249 recorder became completely inoperative in 1945. At present ionospheric data are gathered with

manually operated equipment which is run on a 24-hour-a-day schedule with the assistance of local help. The ionospheric results from this location have been helpful in determining the extent of the equatorial dip in critical frequency and in filling the gap between Huancayo and Puerto Rico for latitude distribution.

The station near Reykjavik, Iceland, was put into operation early in 1944. The site was selected following a survey by Wells, at which time arrangements were made for erection of the necessary buildings and antennas near Camp Waterloo. The successful establishment and operation of this station was due, to a large extent, to the close cooperation and assistance which our staff received from the Iceland Base Command. After the opening of the European campaign, withdrawal of our forces left the staff isolated from immediate military facilities. Operations were continued, however, although under a severe handicap, especially during the winter. The ionospheric data from Iceland were of special significance because of its location along the auroral zone and its proximity to the great-circle path for radio communications between the eastern United States and European countries. After this station had operated for a year simultaneously with the College (Alaska) Observatory, it became apparent that average ionospheric characteristics for Iceland were very similar to those for College. It is interesting to note that for the first time in the expanding program an equivalence of stations had actually been obtained. The two stations had similar geomagnetic and geographic latitudes although widely separated in longitude. The Iceland Station was discontinued July 31, 1945, and the equipment was disposed of in accordance with instructions from the WPC.

In 1944 it became increasingly apparent from the more extensive ionospheric data that *F*-region ionization was distributed more uniformly along geomagnetic latitudes than along geographic latitudes. To clarify this important observation a station was needed at or near the intersection of the geographic and geomagnetic equators in the Pacific. Christmas Island was selected as the best possible approach to this condition, and the Department was requested to establish a station on the island. Since no additional automatic ionospheric recorders were available in the United States, the Signal Corps made arrangements to procure from Australia one of the automatic recorders being constructed for the Australian Radio Wave Propagation Committee at the Radiophysics Laboratory of the University of Sydney. Because it was urgent to get immediate data from Christmas Island, Wells and Huebsch proceeded thither by air with a manually operated DTM recorder; Watts joined the group in the Hawaiian Islands. Following the group's arrival at Christmas Island late in November 1944, regular ionospheric observations were begun December 1, 1944. Wells then proceeded to Sydney, Australia, to test and inspect the Australian apparatus; he also attended meetings of the Australian Radio Propagation Committee and visited the Watheroo Magnetic Observatory.

Following acceptance and packing of the Australian equipment, Wells returned to Christmas Island by air with the entire shipment of nearly two tons; after training and indoctrination with the staff there, he returned to Washington in February 1945. Ionospheric data from this station have been valuable in outlining world-wide characteristics of the ionosphere. Similarity to the results at Huancayo supported the conception of *F*-layer distribution with geomagnetic latitudes. Other ionospheric features at Christmas Island, such as abnormal or sporadic-*E* ionization, show

characteristics which are greatly different from those at Huancayo.

To fill the need for ionospheric data from arctic regions, especially in the North Pacific, a station in the Aleutian Island chain was judged to be essential. A preliminary survey of available sites was made by Lieutenant Commander O'Brien of the Bureau of Aeronautics; on the basis of this survey a site was selected near the Naval Air Base on Adak. Arrangements were completed for the use of certain existing facilities and the construction of additional buildings which were required. Civilian personnel were trained for the station and supplied with a DTM model 3 manual ionospheric recorder together with a full complement of spare parts, tools, and other accessories. Arrangements were made to obtain the necessary gasoline-engine generators locally through the armed services on the island.

Operation of the station was delayed appreciably because of the irregular shipping schedules. Operations were commenced, however, on October 8, 1945. A schedule covering approximately 18 to 20 hours a day was maintained by the two civilian observers under adverse conditions which were aggravated by the necessity of living several miles from the station. Under the adverse weather conditions the operating schedule was occasionally disrupted by failure of transportation. In the spring of 1946 it was possible to transfer the station to a more centrally located site on the island with the advantages of having the laboratory and quarters together and with a dependable source of power from the adjoining air base.

Ionospheric data from Adak have proved to be helpful in filling in some gaps in the world-wide distribution pattern. The results, although satisfactory, were subject to the limitations of a manual recorder operated by a staff of two men. Because of the importance of ionospheric data from arctic regions, it is considered desirable that future plans for operation of the station be based on the installation of automatic recording apparatus at an early date.

Under the immediate sponsorship of the Communication Liaison Branch of the Radio Propagation Section, United States Army Signal Corps, steps were taken to establish additional ionospheric observing stations at Leyte, Guam, and Okinawa. Separate Army crews, each consisting of one officer and a detail of enlisted men, were trained for each station. Manually operated apparatus of DTM design was modified to incorporate a larger indicator unit facilitating the manual operation. At the same time a program of instrumental development was initiated which led to the construction by Sergeant Sulzer of the first working model of a wide-band panoramic ionospheric recorder with only one moving part. In addition to the manual apparatus, each of the teams was supplied with complete components and accessories to provide for the field-construction of a Sulzer model recorder.

The above-mentioned Signal Corps teams conducted ionospheric measurements at Hollandia (New Guinea), Leyte, Guam, and Okinawa. Results of their observations have conclusively established the *F*-region variation with geomagnetic latitudes especially in the equatorial belt. Local services by each group also functioned to provide up-to-the-minute information on radio-propagation conditions to the Army and Navy Commands in their immediate theaters of operation.

A cooperative arrangement with the Army Air Forces resulted in the loan of manually operated stand-by equipment from the Maui Station for a series of sampling ionospheric measurements in the Southwest Pacific by Bramhall. The results of the measurements at Kwajalein

and Eniwetok have been reported in a separate communication by the Air Forces.

Under the auspices of the United States Navy, two complete manual ionospheric recorders were constructed for installation in China. Dr. Paul T. Kwei and his associate, Dr. E. T. Shu, were trained in the operation and maintenance of the first equipment. It was subsequently installed at Loshan, China, the temporary location of National Wuhan University. Personnel and apparatus were flown over the "hump" from Calcutta to Chungking, and thence carried by truck to their destination, where recordings were started early in 1946. Naval authorities in China rendered cooperation and assistance in the establishment of this station.

Naval enlisted personnel were trained in the operation of the second apparatus, originally intended for installation in northern China. The completion of plans was interrupted, however, by cessation of the Japanese war; according to reports received in July 1946, the apparatus was then in storage at Shanghai.

Another manually operated ionospheric DTM recorder was loaned to the Canadian Radio Wave Propagation Committee for installation at St. Johns, Newfoundland, by the Royal Canadian Air Forces. A complete manual DTM recorder was also assigned to IRPL of the National Bureau of Standards for training of personnel to take over the DTM-operated overseas stations.

The continued operation of our three prewar ionospheric observatories was an important contribution because of their strategic locations and long series of data. Activities at the Huancayo Magnetic Observatory, under the direction of Ledig, were expanded to include the operation of four complete field-intensity recorders. Parkinson continued to operate the Watheroo Magnetic Observatory with some assistance from the Royal Australian Air Forces. The large-scale operations at the College Observatory, under the direction of Seaton, were further extended by the addition of a continuous direction-finder program using Navy model DAB-3 direction-finder as part of a large network organized to determine ionospheric effects on direction-finder bearings.

The Department also organized and maintained a coordinated program for collection and dissemination of solar data under the immediate supervision of Shapley. Regular reports of solar observations were received from the United States Naval Observatory, Mount Wilson Observatory, McMath-Hulbert Observatory, and the Climax (Colorado) Coronal Observatory of Harvard University. Other organizations contributed additional useful information on solar activity and sunspot-observations. The solar data were used to provide a basis for short-term forecasts of magnetic and ionospheric conditions. These forecasts were closely coordinated with IRPL and subsequently distributed to the armed forces through IRPL.

With the cessation of hostilities the special wartime activities of this Section are rapidly being transferred to the newly organized Central Radio Propagation Laboratory (CRPL), which supersedes IRPL at the National Bureau of Standards. Activities under the Navy contract which provided for operation of the College Observatory, the coordinated solar program, and some aspects of special operations at Huancayo and Watheroo were terminated on June 30, 1946. The control of the program at the College Observatory was transferred wholly from the Department to the University of Alaska for continuation under a contractual arrangement directly with CRPL from July 1, 1946. The coordinated solar observing program has been completely transferred to the

CRPL. The Huancayo and Watheroo magnetic observatories continue for the present to operate under the Department. The overseas ionospheric stations operated under Army contract have been transferred also to the CRPL. It is anticipated that performance under special war contracts will be completed by August 31, 1946, although some time thereafter will be required to complete reports and accounts.

Research and Development

Electronic clouds. A motion-picture technique of ionospheric recording which was developed in connection with the Signal Corps program resulted in the discovery (Wells, with Watts and D. E. George of the temporary staff) of rapidly moving electronic clouds during magnetic storms—a discovery of considerable note—which are thought to be closely related to the corpuscular emissions from the Sun which result in magnetic and ionospheric storms. Such ionospheric clouds were detected in the Earth's outer atmosphere (ionosphere) during the magnetic storm March 25–26, 1946, at the Kensington Ionospheric Laboratory. The clouds move in from long to short range or out again at intervals of a few minutes. They are first detected at maximum ranges of 800–900 km. They are tracked inward at velocities of 1 to 2 km per second to *F*-layer levels (300–400 km). Occasionally they are seen to move out again at about the same rate. They are observed both during the night when background ionization is low and during the day when background ionization is high. The angle of arrival of the signals cannot be ascertained by the method employed.

These clouds were observed repeatedly during March 25 to 27, 1946—the first opportunity for application of the new recording technique to observation of magnetic-ionospheric storms. The observations were made with the new "panoramic" ionospheric recorder, which was developed with support of the United States Signal Corps and which sweeps over the range 1.5 to 20.0 Mc/sec at adjustable intervals of 5 to 30 seconds. Repetition at such short intervals registers ionospheric fluctuations of short duration which have been missed by earlier instrumentation. The technique has been perfected to the extent that successive records can be projected as motion pictures. Compression of the time-scale as a result of projection provides a sense of continuity which simplifies visualization and interpretation of an otherwise long succession of events.

The principal effects of influx of the clouds are: (1) sudden changes in *F*-layer ionization; (2) rapid changes in *F*-layer heights indicating turbulence which is often progressive from high to low heights and from high to low frequencies; (3) rapid fluctuations of echoes at the lower frequencies with occasional temporary disappearance indicating high absorption.

These clouds may be attributed to an inflow of corpuscles which are bombarding the atmosphere irregularly during magnetic disturbance. These probably are the first direct quantitative observations of such bombardment. They are interpreted as establishing the fact that corpuscular radiation contributes to the net ionization of the *F*-region. The equivalent maximum electronic density is estimated from magneto-ionic theory to be 2×10^5 to 4×10^5 electrons per cubic centimeter. Much of the uninterpreted scatter of the disturbed *F*-region previously seen on slow recorders can doubtless be traced to chance registration of various aspects of rapidly moving clouds. It is considered probable that other higher-velocity cloud-movements exist which will be detected by even faster recordings.

The new technique of ionospheric recording and presentation provides a powerful tool for study of special ionospheric features which occur during magnetic storms, eclipses, radio fade-outs, sporadic *E*, *F*2-scatter, and abnormal stratifications. Projection makes possible quick scanning of an enormous wealth of data, selection of portions for critical study, and visualization of dynamic events of short duration.

Activities at the Kensington Ionospheric Laboratory were devoted exclusively to contract performance. With termination of the Kensington lease, the buildings and facilities were moved to the new Derwood Experimental Laboratory (see below).

Discussions of some of the investigations conducted in connection with the solar program included the following: correlation of solar and geomagnetic observations with conditions of the ionosphere; effects on the ionosphere of the solar eclipse of January 1944 at Huancayo, Peru; eclipse-effects in the *F*2-layer; application of solar and geomagnetic data to short-term forecasts of ionospheric conditions; correlation of magnetic disturbances with intense emission-regions of the solar corona; observations of the green coronal line made at the Fremont Pass Station of the Harvard College Observatory at Climax, Colorado, during August 1942 to July 1945. Other data are now being processed. In general, the forecasting of magnetic and ionospheric storms for a period of several days in advance of the disturbance was successful. A greater percentage of success was achieved —as may be expected—during periods of pronounced recurrences of magnetic activity at 27-day intervals.

Kensington Ionospheric Laboratory and Derwood Experimental Laboratory. The Kensington Ionospheric Laboratory (KIL) has served since 1933 an increasingly valuable purpose; the Kensington Magnetic Laboratory (KML) for special magnetic research for the Navy's Bureau of Ordnance was also established in 1943 on the KIL site (see p. 50). Late in 1945 the owner of this site advised that the lease could not be extended beyond June 30, 1946, because of sale to real-estate developers. Because of past record of accomplishment (see Year Books Nos. 33 to 44), both before and during the war, KIL has been essential to our ionospheric and related researches, which depend heavily on availability of a field-station free from interference of a closely settled neighborhood. It was necessary, therefore, to provide certain minimum facilities not only for ionospheric work but also for other experiments of the Department where accessibility outside the immediate urban area is essential.

A site of 28.7 acres near Derwood, Maryland, about 16 miles north of the Department's main laboratory, was purchased by the Institution in April 1946, to replace KIL. The new station is called the Derwood Experimental Laboratory (DEL). Three buildings and equipment have been moved from KIL, two Quonset huts have been erected and foundations placed for a main laboratory at DEL, and experimental work was under way there before June 30, 1946.

Cooperative Activities

Active participation was maintained in the work of the Wave Propagation Committee and the Executive Council of the Central Radio Propagation Laboratory, as well as close liaison with Army and Navy representatives interested in communication or related problems, and with other scientific organizations. Information and ideas were exchanged with the Australian and Canadian Radio Wave Propagation Committees. Basic ionospheric data are

received regularly from the Union of Soviet Socialist Republics.

Personnel. Berkner, upon completion of nearly five years of active duty as Head of the Electronic Material Branch of the Navy's Bureau of Aeronautics, returned to the Department on January 1, 1946. He was actively engaged in planning and construction of the Derwood Experimental Laboratory until June, when he was loaned to the Services on an important temporary assignment. Wells continued through the report-year as Acting Chief of the Ionospheric Section and with the responsibility for performance under Army-Navy contracts. Seaton remained as Physicist-in-Charge of the College Observatory, College, Alaska, and returned to Washington early in July 1946 (see p. 80).

Activities of the temporary staff were as follows: Shapley remained in charge of the solar research program until its transfer to the Central Radio Propagation Laboratory (CRPL) of the National Bureau of Standards, June 30, 1946. Peavey returned from Christmas Island early in 1946 and transferred to CRPL. Watts was replaced at Maui by Easley, after the latter's return from two years at Clyde, Baffin Island. D. E. George continued instrumental work at Kensington and Derwood, later assisted by Watts. Sullivan and Ventre were assigned to the Trinidad Station to continue operations after return of Johnson. Pendergast went to Christmas Island to assist Huebsch. Gammon was assigned to Maui to assist Easley. Halpin and Stansbury installed and operated the manual ionospheric station at Adak. Goldman accepted commercial employment after his return from Clyde. Members of the College Observatory staff included Wolff, Wilder, West, St. Amand, Atkinson, and Rolfe. At the office, Miss Follin continued special investigational work, and Miss Puffer, and subsequently Miss Kospetos, acted as secretary for the Section.

Reports and Papers

Published reports by members of the Section are listed in the bibliography. In addition, technical papers were delivered at the convention of the Institute of Radio Engineers in New York, the URSI-IRE meeting in Washington, the IRE meeting at Red Bank, New Jersey, and the Department of Commerce lecture series on electronics at Washington, D. C. Extra copies of the film "Motion pictures of the ionosphere" illustrating the discovery of rapidly moving clouds were circulated to several cooperating laboratories.

The lecture by Berkner on "Navy airborne radar" presented before the Winter Technical Session of the Institute of Radio Engineers in New York on January 25, 1946, and that on "Military and naval electronics equipment" presented in the Department of Commerce series on electronics, were based on a comprehensive paper by Berkner entitled "Naval airborne radar." That paper is being published in the *Journal of the Institute of Radio Engineers.* It discusses military and naval electronics equipment, with particular emphasis on aircraft radar. Certain types of equipment which played an important part in World War II are described, with especial attention to microwave design. The wide variety of applications of airborne radar is illustrated, and the fundamental elements of such systems are described. The basic radar range and beamwidth equations are discussed briefly in the light of their controlling influence on design, as well as some operational requirements affecting design.

NUCLEAR PHYSICS

Tuve returned to duty as Chief Physicist late in February 1946, after his service as Director of the Applied Physics Laboratory of Johns Hopkins University at Silver Spring, Maryland. His time since then has been spent in reviewing the activities of the nuclear-physics program and in study of the Department's general postwar program, preparatory to becoming Director on July 1, 1946. Cowie had charge of the 60-inch cyclotron with the assistance of Ksanda, P. Johnson, and Buynitzky. Heydenburg of the nuclear-physics group resumed his place on the staff in February after having been engaged at the Applied Physics Laboratory in war research. The continued absence of Roberts, Hafstad, and G. K. Green on war problems throughout the report-year greatly reduced the nuclear-physics program. Little, of the Instrument-Shop, was assigned to assist Heydenburg after the latter's return. The nuclear-physics group included part-time guest investigators as follows: C. L. Critchfield (from May 27); David R. Inglis (from February 18); and E. Ney and R. Nieset (June 5–18).

Electrostatic High-Voltage Generators

Beginning in February 1946, activities were resumed in nuclear-physics research and related work looking toward the postwar program. Heydenburg and Little, assisted two days a week by Dr. David Inglis, of the Department of Physics of Johns Hopkins University, undertook the task of bringing the Department's high-voltage equipment back into operation during February.

Instead of undertaking a program of refinement of apparatus, it seemed desirable to start making actual measurements in nuclear physics as soon as possible, so the 1,000,000-volt electrostatic generator was reconditioned immediately. Preliminary measurements were begun on the angular distribution of the disintegration protons from the reaction $O^{16} + D$ yields $O^{17} + p$. Angular distribution experiments on the lighter elements are important in the study of the energy-levels of the nucleus. In the reaction above, there are two main proton groups which are being carefully examined with monoenergetic bombardment beams. The purpose of these studies is to seek effects which may arise from spin-orbit coupling of the "extra" neutron in the O^{17} nucleus. The short-range-proton group shows a marked angular dissymmetry.

During a visit to the Physics Department of the University of Wisconsin, Heydenburg discussed at length with Professor R. G. Herb and others the difficulties encountered with the Department's pressure-type high-voltage generator. As a result the following important features are being considered:

(1) Increase in a given tank pressure beyond the point of failure in the column supporting the high-voltage electrodes does not usually improve the behavior.

(2) The column corona-point system for voltage-distribution must be carefully made, probably by using needle points accurately spaced from the discharge plate. The voltage-distribution down the column may probably be improved by installing a new corona-point system which would draw a current of at least 200 microamperes; it is important that none of this current be lost from the column to the outer wall. It is desirable that the accelerating tube be tied into the corona-ring system at every tube-section (not possible on our tube because tube-section lengths are not a multiple of the ring-separation). Herb does not use ring-shields near the charging belt, but shields the belt opening to the

high-voltage electrode and requires that the charge carried in and out of the electrode by the belt be equal. Since our corona-rings are not spaced to limit the maximum voltage by spark-over, small sphere-gaps set at proper spark-over distance should be installed; this can be done with 2.5-inch hemispheres mounted on plates near the porcelain columns. Such gaps would offer a lower impedance path for spark-over and would protect the corona-points from being burned from sparks.

(3) Regarding our accelerating tube, it was concluded that it would be a mistake to use porcelains of smaller diameter than we have, because of consequent reduction of pumping speed. If our tube will not withstand the voltage required after improvement of the voltage-distribution along the column, then a re-entrant-type electrode of design similar to that at Wisconsin, but with a larger inner diameter of electrode—say 10 inches—should be designed; there is no indication that the diameter of the electrode is at all critical in the design of the tube. Because of difficulty in securing porcelain tube-sections at present, tube-sections made of Micalex (a General Electric product which is made of bound mica and glass and can be machined) are being tried, and give good promise of being equal or superior to porcelain.

Future usefulness of pressure high-voltage machines apparently lies in greater precision in beam energy. The machine at Wisconsin is equipped with an electrostatic deflector-type stabilizer in which the molecular beam is deflected electrostatically and allowed to fall on a set of split plates. The current to these plates controls the corona-current from a set of points directed at the high-voltage electrode, in such a way that when the beam energy is too high the corona-current is increased to lower the voltage; this system permits maintaining accuracy of beam-energy of 0.1 per cent. By designing a larger electrostatic analyzer system which will bend the beam through 90°, the Wisconsin group hopes to improve accuracy by another order of magnitude, namely, to 0.01 or even 0.005 per cent. A control system similar to the one at Wisconsin should be installed on our pressure-generator; it would be profitable to install a somewhat simpler version on the 1,000,000-volt machine, using the current from our resistance voltmeter as the controlling source and the large corona-arm now present as the corona-system to be controlled.

It appears that the Department's pressure-generator should be one of the most useful machines in the country if it can be made to operate reliably at four or five million volts, which might be accomplished with a better voltage-distribution down the insulating column.

Improvements are already in progress on the pressure-type electrostatic generator. These improvements include a new vacuum safety system (completed), an adjustable corona rod to control the voltage, and a new generating voltmeter. Tests so far on the modified accelerating tube (which was completed in 1941) indicate that it is not a great improvement over the original tube. A new tube, patterned after the Wisconsin type, may be necessary before reliable operation above 3,000,000 volts is possible.

Cyclotron

During the year the cyclotron continued its steady operation, and over 1300 hours of target bombardment provided materials for numerous research programs.

It was possible during the year to produce one sample of beryllium as a by-product that had more than 100,000 microampere hours of deuterons on it, providing a source of Be^{10}, probably the largest in the

world. The radioactivity of this isotope presents problems both as to the theory of the structure of light nuclei and as to the theory of beta decay. Chemical separation of this target has resulted in a sample of beryllium hydroxide that seems to have enough of the extremely long-lived Be^{10} to be readily detectable by the Geiger counter, and Dr. Charles Critchfield, of George Washington University, collaborating with Tuve and Cowie, will attempt to determine some of the physical characteristics of this isotope.

As in the past year, most of the bombardments were applied to biophysical research; some of the more interesting details are outlined here.

Collaborative studies by the Division of Zoology of the United States Public Health Service, the Moore General Hospital of the United States Army, and this Department produced significant results. Six Army men, infected with *Schistosoma japonicum,* were given single doses of tartar emetic prepared with radioactive antimony. The excretion rates by urine and feces and the blood levels were determined over a 7-day interval. Analysis of the data obtained showed that the process of transfer of the tartar emetic after intravenous injection to other body fluids and tissues, and also the excretion mechanism, are linear functions of the initial antimony blood levels. A system of linear differential equations is thus defined that describes the number of processes of antimony transfer, the rates of transfer, and the capacity of the several parts of the mechanisms involved. The rates of excretion were found proportional to blood levels for the six individuals studied. Three mechanisms were found in the elimination of the antimony from the blood stream. Five minutes after injection 90 per cent of the antimony had left the blood stream. Ten per cent of the antimony injected is excreted in the urine or feces in 24 hours, and the rest is excreted at such a rate that half of the remaining antimony is eliminated in about four weeks. More data on the initial rapid transfer of antimony from the blood stream would provide a means of predicting to what extent blood levels could be controlled by the rate of injection.

Repeated dosage of tartar emetic to a single patient, following the schedule of Army treatment for *Schistosoma japonicum,* showed that, although a large percentage of the antimony injected is retained in the body (mainly in the liver), this retained antimony is not physiologically active, else repeated doses would have approximately the same toxicity as large single doses. It can be postulated, therefore, that the antimony does not exist as tartar emetic, which is soluble and diffusible, but has been converted very shortly after its injection to some new compound of antimony.

The studies on laboratory animals have similarly shown a very rapid removal of antimony from the blood stream. Other studies have shown that the adult parasites have a specific uptake of antimony, and it is reasonable to assume that the therapeutic value of antimonials is due to the high antimony level in the blood soon after injection. The rapid drop in blood levels suggests that antimony should be given in more frequent doses rather than by the customary three injections per week, this technique permitting the maintenance of a higher residual antimony level in the blood.

Anomalously, white rats have shown a marked difference from humans in the uptake of both antimony and arsenic. When sodium arsenite is injected intraperitoneally into a large number of white rats, the arsenic concentration rises rapidly after the first few hours and in 24 hours reaches a concentration 100 times greater

than that found in any other animal, including man. Even 14 days later this concentration is not greatly reduced and the arsenic is retained by the red blood cells. Liver tissues after perfusion were an order of magnitude lower in arsenic concentration, indicating that the arsenic concentration in the blood was responsible for the greater part of the arsenic found in the liver. It appears that the sodium arsenite, as the arsenical injected, is rapidly converted to some unknown arsenic compound by the chemical constituents of the red blood cell and is not eliminated very rapidly in this new form. Some of the initial tartar emetic, however, is probably eliminated as such in the first few minutes after the injection, since liver and other tissues showed a slight initial uptake of arsenic which dropped rapidly after a few hours. It was found that the blood of the white rats would account for almost 100 per cent of the injected dose 24 hours after its administration. The significance of the anomalous blood level is obvious, namely, that conclusions from therapeutic and physiological studies on arsenic and antimony based on similarity of a white rat's physiology to that of the human will prove erroneous.

The above studies were made by a cooperating team consisting of Drs. Fred J. Brady, Fred C. Bartter, and Arthur T. Ness of the United States Public Health Service, and Cowie and Forbush of the Department.

The Naval Medical Research Institute in collaboration with the Department completed several studies on the distribution of antimony inhaled as stibine. Radioactive antimony administered as stibine gas (SbH_3) to chicks both normal and infected with *Plasmodium gallinaceum,* and to normal guinea pigs, was measured in the blood and tissues at successive time-intervals following administration. Significant differences were not apparent between distributions in normal and infected groups. The concentration of antimony in the blood stream exhibited a smoothly decaying curve, decreasing more rapidly in the guinea pig than in the chick. The red cells contained a much higher concentration of antimony than did the plasma. The concentration-curves for antimony in lung, brain, muscle, and fat were generally similar to that for blood, whereas those for the liver, and to a lesser extent the spleen, passed through a maximum about one hour following treatment. Concentration-curves for the kidney and heart were of variable shape. Approximately 4 hours after treatment, the tissue antimony levels became constant with respect to order of rank; liver, spleen, and kidney were higher than whole blood; all other tissues showed less than the blood but as much as or more than the plasma.

It appears that stibine during the gaseous exchange in the lungs of these animals is taken up almost entirely by the red cells. This stibine is almost instantaneously decomposed, the antimony being trapped within the red blood cells in the colloidal form as metallic antimony. This rapid decomposition in the red blood cells is catalyzed by the hemoglobin and the methemoglobin, which converts the metallic antimony to Sb_2O_3, which in turn slowly dialyzes out of the cell into the plasma. This accounts for the low plasma and tissue levels as contrasted with the early red-blood-cell concentrations of antimony.

Further studies were made on the distribution of radioactive antimony in hamsters infected with *Schistosoma mansoni,* with particular reference to the accumulation in the thyroid. A series of hamsters infected with *Schistosoma mansoni,* and a series of normal control animals, were injected intraperitoneally with a single dose (0.8 mg/kg) of tartar emetic into which radio-

active antimony in tracer amounts had been synthesized. A marked accumulation of antimony occurred in the liver and subsequently in the thyroid in both controls and infected animals. In the parasites, the concentration of antimony was greatest within an hour after the injection. The relative order of tissue and parasite concentrations at 48 hours was similar to that found by others in dogs infected with *Dirofilaria immitis*, reported by the United States Public Health Service workers. These results suggest that perhaps the toxic symptoms of antimony therapy are related to its accumulation in the thyroid as well as in the liver.

Drs. Louis A. Flexner and Walter S. Wilde, of the Department of Embryology of the Carnegie Institution of Washington, collaborated with Cowie and the cyclotron group in the continued study of the permeability of the placenta to various isotopes. It has been shown by Flexner and his coworkers that in the case of sodium the fetus receives across the placenta about 50 times as much as is incorporated in the growing tissues of the fetus, and in the case of water about 150 times as much. Inorganic phosphate, in sharp contrast, is supplied to the fetus in quantities approximately equivalent to the total phosphorus needed for growth, and there is no evidence of a safety factor of any considerable magnitude such as was found with the sodium and water. These findings suggest the hypothesis that maternal phosphorus stores are essential in the maintenance of growth during pregnancy, and that these stores may be organic molecules from which phosphorus can be liberated as needed by enzyme activity. Studies of radioactive chlorine are now under way to determine its permeability with the same type of placenta.

Ksanda, Buynitzky, and P. Johnson spent full time on the operation and maintenance of the cyclotron during the entire year. Buynitzky was responsible for the daily operation and the general improvements in the cyclotron. Ksanda was in charge of the cyclotron shop and assisted in the radioactivity measurements of numerous biological and chemical samples as the problems progressed. P. Johnson spent some time on electronic instrumentation, in the improvement of radioactive measuring equipment, and in the maintenance of the radio-frequency supply for the cyclotron. A report was prepared by Roberts and Cowie on the radio-frequency supply for this cyclotron. Attempts are now under way to get a deflected beam out of the cyclotron, looking forward to future biological and nuclear-physics problems as members of the staff return from their various war activities.

During the year numerous bombardments were made for many organizations, both governmental and institutional, in or about Washington: the Department of Agriculture, the National Bureau of Standards, Catholic University, Camp Detrick, United States Army, Public Health Service, and others.

Miscellaneous

The Ohio Postwar Planning Commission was supplied on request with detailed description and plans of the 60-inch cyclotron and its special laboratory together with data on cost of construction at the Department; the Commission had under consideration provision of such facilities under Ohio State University to serve the large region of educational, industrial, and medical and surgical centers in and adjoining the state of Ohio.

Dr. J. D. Cockroft was supplied, also on request, with 85 drawings and photographs showing the CIW cyclotron in detail, as well as its building, for use by the National Research Council of Canada.

To assist in completion of the new 210-cm cyclotron at the University of Upsala (Sweden), Dr. T. Svedberg, following several inspections at the Department by himself and colleagues, was provided with over 100 drawings showing details of construction of the cyclotron and its appurtenances.

Publications on nuclear-physics research are listed in the bibliography. A large number of lectures were presented by Tuve, Hafstad, and Cowie on the cyclotron and the biological and medical researches made possible by its use.

As in 1945, the Annual Conference on Theoretical Physics was not held because of limitations of time and travel. It is planned to resume this annual meeting during the coming year.

FIELD-WORK AND REDUCTIONS

MAGNETIC SURVEY

With reference to future desiderata for magnetic-survey operations and potential improvements, comprehensive reviews were prepared by Vestine, McNish, and others of the staff; these are briefly summarized elsewhere in this report (see pp. 39, 49). The outstanding problems and improved techniques—largely the result of applications made during the war and now available for scientific improvement looking to constructive rather than destructive use—point the way to great potential improvements in forwarding knowledge and understanding of geomagnetism through continued surveys to be appropriately undertaken by international cooperation.

Isomagnetic world charts in declination (D), horizontal intensity (H), and vertical intensity (Z) in 17 sections each were completed, and nearing completion are those in inclination (I), north intensity (X), east intensity (Y), and total intensity (F) in three sections each; this work is being done under Vestine's supervision. Isoporic world charts in the foregoing seven elements, referred to in last year's report, were completed for epochs 1912.5, 1922.5, 1932.5, and 1942.5. With their aid, embracing all available magnetic information, observations at field-stations as early as 1905 could be successfully utilized in constructing charts in the seven components of the main field for epoch 1945. The foregoing charts were drawn, so far as possible, on a basis independent of results shown on previous isomagnetic charts. They constitute the first series of world charts complete in all seven elements, and with full attention to line-configurations near important singular points in field.

Wallis and J. W. Green continued final revisions of reductions of magnetic observations. Results from cooperative observations in the field were checked and summarized as received and added to the manuscript for a volume in the series of the Department's "Researches" on results on land and sea from 1927 to 1946. The revised constants and formulas for sea-deflector CIW 5 used during Cruise VII of the *Carnegie* agree closely with the preliminary ones computed from instrumental comparisons at Washington preceding the cruise; only minor changes are required in the preliminary values for final tabulations of data obtained.

Field-Operations and Cooperative Surveys

The Department continued its policy of encouragement and aid to other agencies

in cooperative magnetic surveys on land, at sea, and by air. This was mainly done through the loan of magnetometers with inductors or dip-circles and other accessories for surveys in North, Central, and South America, South Australia, Northern Australia, New Zealand, British East Africa, Belgian Congo, South Africa, and North Polar regions—as summarized below—and also by new instrumentation. International magnetic standards were maintained in cooperation with the United States Coast and Geodetic Survey.

Africa. Observations in Tanganyika Territory using CIW magnetometer and inductor 13 were continued by Dr. A. Walter, Director of the British East African Meteorological Service.

CIW magnetometer-inductor 17 remained on loan to Dr. G. Heinrichs in the Belgian Congo, where it was used at the Elisabethville Magnetic Observatory. It was later forwarded for use at the Manhay Observatory of the University of Liége, Belgium.

Australia. CIW magnetometer-inductor 18 remained on loan to the Australian government, and valuable and extensive surveys are being undertaken by Chief Geophysicist J. M. Rayner and R. S. Richardson.

CIW magnetometer 6 and dip-circle 226 were continued on loan to Astronomer G. F. Dodwell.

New Zealand. CIW magnetometer-inductor 27 was used in extensive resurveys of New Zealand by Director H. F. Baird of the New Zealand Magnetic Survey, New Zealand Department of Scientific and Industrial Research.

North, Central, and South America. CIW magnetometer 8 and dip-circles 241 and 242 and appurtenances were made available for use in the Arctic by J. B. Campbell of the United States Coast and Geodetic Survey.

CIW universal magnetometer 19 was loaned to Colonel P. S. Reinecke, of the United States Lake Survey Office, Detroit, for surveys in the Great Lakes region.

CIW magnetometer-inductor 28 was used by Major S. Graceras, Chief of the Division of Geodesy, Military Geographic Institute, Uruguay, in surveys of Uruguay.

Polar regions. Instrumental loans for work in the Arctic were as indicated above. In addition, memoranda and comments were prepared for the program of the Arctic Institute of America. In connection with conferences in November 1945 bearing on a suggested program of the American Air Forces for an aerial magnetic survey of the North American Arctic, which included representatives of the United States Hydrographic Office, the United States Coast and Geodetic Survey, the Office of Chief of Engineers, the Office of the Assistant Chief, Air Staff Corps, and of the Department (McNish), the Director of the Department submitted the following statement: "A project for which there is immediate need is the extension of magnetic surveys over the Arctic cap. Isomagnetic charts now available for navigation in this region, so important for present and future transportation, are of decidedly inferior quality, and the only remedy is the making of additional magnetic observations required to improve existing charts. Although new radio methods of navigation have come to the fore rapidly, it is necessary to observe that their scope and utility in high latitudes are not so great. In connection with this program it is technically feasible to do a part at least of this magnetic survey by planes carrying measuring apparatus for magnetic force and direction." Most of the automatic observational instruments needed and developed during the past five years are available or so developed as to make possible any necessary further improvement adapting them for use as absolute instruments. The resulting increased accuracy of isomagnetic charts and study of the area around the magnetic pole would be of inestimable value, particularly if extended to other regions, and perhaps of fundamental importance to basic physical theory.

Memoranda were also prepared for a proposed expedition to the Antarctic Continent.

OBSERVATORY-WORK

Johnston, Chief of Section, was on sick-leave until June 30, 1946, when he was placed on the retired basis. In his absence the responsibilities of the Section were carried by Scott. The period of so-called reconversion, following World War II, found the Section continuing its usual program. The reduction of magnetic data and computations in connection with the analysis of the magnetic results from the observatories were continued by Scott and Miss Balsam. Torreson, with the assistance of Mrs. Crow (until February 14, 1946) and Miss Walburn (from February 25, 1946), was engaged in the preparation of manuscript for offset printing of the final two volumes of the *Carnegie* series, namely Oceanography III (atmospheric-electric data) and Oceanography IV (future magnetic, electric, and oceanographic surveys), and of the magnetic results at the Watheroo Magnetic Observatory, Miss Balsam also assisting in the last.

The magnetic, earth-current, and ionospheric programs at Watheroo and Huancayo observatories were continued. Weekly summaries of magnetic and ionospheric data, predicted values of maximum usable frequencies for various distances, and current forecasts of conditions having probable effects on radio communication were supplied various governmental bureaus and organizations.

Continuous records of the three magnetic elements, and of heights of the ionosphere by means of both multifrequency and fixed-frequency transmission, were made at Watheroo, Huancayo, and College. Atmospheric potential-gradient, positive and negative conductivity of the atmosphere, earth-currents, some solar observations with the Hale spectrohelioscope, and meteorological elements were recorded at Watheroo and Huancayo. The cosmic-ray meter, signal-intensity equipment, and the three-component seismographs also were in operation at Huancayo.

The reduction of the magnetic observations at Watheroo and Huancayo was completed for the year 1945. The mean annual values of the magnetic elements for all days of 1944 and 1945 are shown in table 1; preliminary values for College, Alaska, are given under "Operations at observatories."

The collection of three-hour-range index *K* (on scale 0, very quiet, to 9, extremely disturbed) from contributing world magnetic observatories was continued by the Department. This cooperative scheme is a splendid example of joint effort among different peoples. The *K*-index provides a homogeneous running record of the transient effects of solar corpuscular radiation by measuring the intensity of the geomagnetic activity caused by the electric currents produced around the Earth by that radiation. Initiated in September 1939 by the International Association of Terrestrial Magnetism and Electricity to meet the requests made by the International Union of Scientific Radiotelegraphy and other bodies for information concerning the magnetic activity in greater detail than the daily magnetic character-figures, the program was successfully carried out despite interference by war with its growth. Correspondence with numerous observatories prohibited during the war-period has now been resumed. Reports of *K*-indices were received from 27, 29, 28, 27, 30, and 32 world-observatories for the years 1940 to 1945, respectively. A short paper entitled "Mean *K*-indices from thirty magnetic observatories and preliminary international character-figures for 1944" was

prepared for publication in the *Journal of Terrestrial Magnetism and Atmospheric Electricity,* as were also several "Letters to editor." Selections of the five international quiet and disturbed days were made for the months of 1945.

"Reports of geomagnetic activity," DTM CIW nos. 441–492, from ten observatories (seven American-operated observatories, also College, Toolangi, and Godhavn) were compiled and distributed weekly geomagnetic observatories of the world for publication in the form of a thesaurus was continued by Fleming and Scott.

Unusual activity in the field of science the world over has emphasized the need for reassessment of many scientific efforts and objectives in order to keep pace with the changing world. Older programs and techniques undoubtedly will undergo considerable review and perhaps change. In this connection, members of the Section

TABLE 1

ANNUAL VALUES OF THE MAGNETIC ELEMENTS AT THE WATHEROO AND HUANCAYO MAGNETIC OBSERVATORIES AS BASED ON MAGNETOGRAMS FOR ALL DAYS, 1944 AND 1945

YEAR	DECLINATION, *D*	INCLINATION, *I*	INTENSITY-COMPONENTS					LOCAL MAGNETIC CONSTANT, *G*
			Horizontal, *H* (γ)	Total, *F* (γ)	North-south, *X* (γ)	East-west, *Y* (γ)	Vertical, *Z* (γ)	
WATHEROO MAGNETIC OBSERVATORY								
1944.....	3°01′1 W	64°25′2 S	24745	57310	24711	−1303	−51693	35782
1945.....	2 57.9 W	64 25.4 S	24767	57368	24734	−1281	−51746	35816
HUANCAYO MAGNETIC OBSERVATORY								
1944.....	6 34.8 E	2 10.3 N	29367	29388	29174	3365	1114	29372
1945.....	6 30.5 E	2 08.8 N	29329	29350	29140	3324	1099	29334

during the report-year. Regular quarterly reports of American character-figures and *K*-indices were prepared for publication. Final summaries of American mean *K*-indices and magnetic-character figures, including graphs, were completed for 1945 and published.

The *u*-measure of magnetic activity, derived from differences of daily means of horizontal intensity, was compiled through 1944 for the American-operated observatories.

The compilation of annual values at

submitted comments and attended conferences to discuss future programs of scientific work.

Cooperative work in magnetism and atmospheric electricity was continued with various observatories, as was also the practice of loaning field-instruments and equipment to foreign governments and to the United States Coast and Geodetic Survey. The Department cooperated with the Danish government in operating the Godhavn Magnetic Observatory in Greenland.

Giesecke, of the Huancayo Observatory,

spent several months in Washington, during which time he discussed at length some improvements and alterations—suggested by Ledig and the Huancayo staff—in the work of that Observatory.

Scott, Chernosky, and Giesecke visited the Bureau of Standards Radio Station near Sterling, Virginia, to adjust CIW visual-recording *H*-variometer (magnetograph 3) in use there, also to familiarize themselves with the equipment and researches.

Additional preliminary surveys of magnetic conditions at the Naval Ordnance Laboratory at White Oak, Maryland, were made by McNish and Scott as follows: Large Projects and Model buildings; sites of proposed Long Field and Spherical Field laboratories; and site of station (reoccupation) near Quiet House.

CIW magnetometer-inductor 16 was standardized at the Cheltenham Magnetic Observatory in June 1946; this instrument will replace magnetometer 10 and earth-inductor 5 pending overhauling in the Department's instrument-shop and restandardization.

Following intercomparisons and use as a standard at the Elisabethville Magnetic Observatory, CIW magnetometer-inductor 17 was taken by Dr. G. Heinrichs to the Manhay Magnetic Observatory in Belgium for observational use there until such time as new absolute instruments are obtainable.

The Department loaned field-instruments, consisting of theodolite-magnetometer 8, dip-circles 241 and 242, and Berger theodolite 3578, to the United States Coast and Geodetic Survey for use on the proposed arctic Nanook Expedition. A list of organizations concerned with terrestrial magnetism was also prepared for the United States Coast and Geodetic Survey.

Operations at Observatories

Watheroo Magnetic Observatory, Watheroo, Western Australia. *The Watheroo* Magnetic Observatory is situated in latitude 30° 19′.1 south and longitude 115° 52′.6 east of Greenwich, 244 meters (800 feet) above sea-level.

Weekly determinations of the base-line values of the Eschenhagen variometers were made in the absolute observatory using CIW magnetometer 7 and CIW earth-inductor 2.

TABLE 2

Scale-values of magnetographs, Watheroo Magnetic Observatory, 1945

Month	Scale-values in γ/mm			
	Eschenhagen		la Cour	
	H (reduced to base-line)	*Z* (means of daily values)	*H*	*Z*
January...	2.43	3.59*	4.52	3.46
February..	2.44	3.68	4.55	3.43
March.....	2.44	3.70	4.39	3.55
April.....	2.43	3.70	4.54	3.62
May.....	2.44	3.43*	4.61	3.72
June.....	2.45	3.59*	4.63	3.61
July†.....	2.45	3.56*	4.63	3.94
August....	2.43	3.54	4.66	5.24
September.	2.45	3.58	4.61	5.53
October....	2.45	3.55	4.62	5.46
November.	2.46	3.49*	4.65	5.59
December..	2.44	3.30	4.57	5.34

* Mean value of several base-line shifts.
† Orientation-tests were made during July.

The preliminary mean values of the magnetic elements for all days of 1945, as deduced from the Eschenhagen magnetograms, referring the elements to the north-seeking end of the needle and reckoning east declination and north inclination as positive, indicate annual changes as follows: declination, +3′.2; horizontal intensity, +22 gammas; and inclination, −0′.2 (see table 1 for mean annual values).

As a criterion of geomagnetic activity, three-hour-range *K*-indices, on a scale of 0 to 9, were assigned from the Eschenhagen magnetograms and transmitted daily to Mount Stromlo, weekly to Washington, and monthly to the Radio Research Board at Sydney. Table 3 shows the mean monthly *K*-indices for 1945 for the three-hour periods.

recorder to volts per meter, were made during September 1945 and gave a value of 1.06—a good confirmation of previous determinations. Weekly calibrations of the recording electrometer were made. Table 5 gives the monthly mean air-potentials for 1945 in volts per meter, using a reduction-factor of 1.10.

Positive and negative air-conductivities were

TABLE 3

MONTHLY MEAN FOR THREE-HOUR-RANGE *K*-INDICES, WATHEROO MAGNETIC OBSERVATORY, 1945

MONTH	GREENWICH MEAN HOURS								MEAN FOR MONTH
	00–03	03–06	06–09	09–12	12–15	15–18	18–21	21–24	
January....	1.8	2.0	2.0	2.2	2.0	1.9	2.0	1.9	2.0
February...	1.7	1.9	2.0	2.1	2.2	2.2	2.1	1.6	2.0
March.....	2.0	1.9	2.1	2.6	2.7	2.8	2.2	2.4	2.3
April.....	1.7	1.7	2.2	2.3	2.3	2.2	2.0	1.7	2.0
May.....	1.6	1.9	2.0	2.0	2.0	2.2	1.9	1.7	1.9
June.....	1.4	1.6	1.9	1.5	1.5	1.3	1.4	1.2	1.5
July.....	1.7	2.1	1.7	1.8	1.8	1.7	1.6	1.7	1.8
August.....	1.5	1.8	1.9	1.7	1.6	1.9	1.7	1.4	1.7
September..	1.8	2.0	2.1	2.2	2.3	2.0	2.0	1.9	2.0
October....	1.9	1.8	1.8	2.0	2.5	2.4	2.2	2.3	2.1
November..	1.6	1.8	2.0	1.8	2.0	1.8	1.8	1.9	1.8
December ..	2.1	2.3	2.3	2.4	2.7	2.4	2.2	2.4	2.4
Year.....	1.7	1.9	2.0	2.0	2.1	2.1	1.9	1.8	1.9

Seven magnetic storms were recorded during 1945, and table 4 gives the essential details of these disturbances.

The continuous registration of earth-potentials, using a system of electrodes which has been described in previous reports, was carried on throughout the year, and loss of trace from instrumental causes was small although magnetic storms necessitated the rejection of some days in the tabulations. Scalings and reductions are current and the diurnal-variation curves of the four lines give consistent results. The conducting lines were regularly patrolled and defects promptly remedied.

Air-potentials were continuously recorded throughout the year and the results tabulated and reduced. Standardization observations, for the reduction of the values from the re-

TABLE 4

DETAILS OF MAGNETIC DISTURBANCES RECORDED AT WATHEROO MAGNETIC OBSERVATORY DURING 1945

DATE	RANGES		
	H (γ)	*D* (′)	*Z* (γ)
March 12–13.....	83	16	103
March 14–15.....	117	14	82
March 25–26.....	114	16	100
March 27–28.....	138	32	182
April 1.....	100	21	115
October 23–25.....	137	18	133
December 13–14.....	126	18	132

continuously recorded throughout the year and weekly calibrations made. Adjustments to the apparatus were made as required, and scalings and reductions were kept current. Table 5 gives the monthly mean values of positive and negative conductivities, their sums, and ratios.

The automatic multifrequency ionospheric recording apparatus was in continuous operation, the only breaks in registration being occasioned by maintenance, calibration-checks, minor repairs, and adjustments to the apparatus. Various replacements of wearing parts were made as required. Daily reports of hourly ionospheric conditions were transmitted to Mount Stromlo through the Department of Air, and copies of monthly mean hourly values were sent to the Department of Air, the Radio Research Board at Sydney, the Department of Scientific and Industrial Development of New Zealand, His Majesty's Australian Navy, and Washington. Photographic copies of ionospheric tabulations were also supplied to various organizations. Table 6 gives the mean monthly values of ionospheric data, and table 7 shows the mean hourly values for the calendar year 1945.

The full program of observation and automatic recording of the meteorological elements was maintained. Coded reports on weather were prepared and transmitted thrice daily to the RAAF forecasting station in Perth, and monthly summaries of meteorological data were regularly supplied to the Commonwealth Weather Bureau in Melbourne. A daily journal of weather was kept. The reduction of the meteorological data is reasonably current. Table 8 shows the monthly rainfall at the Observatory during 1945.

The continued manpower shortage limited all repair, maintenance, and improvement work on buildings and site to that urgently necessary.

W. C. Parkinson remained until April 1946, when F. W. Wood took his place as Observer-in-Charge. The former had been in charge at Watheroo since 1929 almost con-

TABLE 5

PRELIMINARY MONTHLY MEAN VALUES OF ATMOSPHERIC-ELECTRIC ELEMENTS, WATHEROO MAGNETIC OBSERVATORY, 1945

MONTH	POTENTIAL-GRADIENT			AIR-CONDUCTIVITY, UNIT 10^{-4} ESU				
	No. selected days	Reduction-factor	Value* (v/m)	No. selected days	λ_+	λ_-	$(\lambda_+ + \lambda_-)$	(λ_+ / λ_-)
January	19	....	117.4	18	1.33	1.18	2.51	1.13
February	15	....	82.9	17	1.64	1.59	3.23	1.03
March	13	....	81.6	14	1.76	1.69	3.45	1.04
April	14	....	78.3	13	1.90	1.80	3.70	1.06
May	21	....	69.3	20	2.31	2.10	4.41	1.10
June	11	....	67.6	18	2.08	1.75	3.83	1.19
July	17	....	84.6	20	2.10	1.83	3.93	1.15
August	15	....	85.8	9	1.83	1.47	3.30	1.24
September	22	1.06	87.1	21	1.53	1.51	3.04	1.01
October	26	....	85.7	10	1.61	1.36	2.97	1.18
November	19	....	96.6	23	1.55	1.44	2.99	1.08
December	21	....	104.4	26	1.43	1.34	2.77	1.07
Totals and means	213	1.06	86.8	209	1.76	1.59	3.34	1.11

* Using reduction-factor 1.10.

tinuously except for two field-trips, during one of which, November 1929 to April 1930, Wood was Acting Observer-in-Charge. Wood has had much experience in geomagnetic, geoelectric, and ionospheric work, having been Observer on the staff at Watheroo during 1926–1933 and having served for some years with the Radio Research Board of Australia. W. D. Parkinson continued as part-time Junior Observer until early in April, when W. C. Parkinson and he were instructed to proceed via the Cape of Good Hope and England to Washington and report for duty there. Because of scarcity of steamer-travel accommodations, they could not leave Australia until June 1946. Parkes, Overheu (from December), and Hudson (from January) were Junior Observers; McCall was mechanic, assisted by Loney (to August 1945) and Bevis (from August).

The helpful assistance of the Australian Department of Air with personnel and courtesy in transmitting records and data to Washington, and the privilege of custom-free entry of supplies and equipment accorded by the Commonwealth Department of Trade and Commerce, are gratefully acknowledged as important factors in the successful maintenance of the Observatory.

Despite great difficulties of the emergency and the ever-increasing volume of work, each member of the staff labored enthusiastically and efficiently to increase the store of, and to maintain the high standards of, another year's geophysical data.

Huancayo Magnetic Observatory, Peru. Partly because of its position practically on the magnetic equator and partly because of the many branches of the geophysical sciences being observed there, the Huancayo Magnetic Observatory is the most important geophysical observatory in the Western Hemisphere, and probably in the world. It is situated in the Central Valley of the Peruvian Andes, 8½ miles west of the town of Huancayo, in longitude 75° 20′.4 west and latitude 12° 02′.7 south, and at an altitude of 11,000 feet (3350 meters) above sea-level.

Recording of magnetic variations was begun in 1922, more than two sunspot-cycles ago, and through the years that have passed

TABLE 6

PRELIMINARY MEAN MONTHLY VALUES OF IONOSPHERIC DATA, WATHEROO MAGNETIC OBSERVATORY, 1945

MONTH	$h^{min}F1$ (km)	$h^{max}F2$ (km)	$h^{min}F2$ (km)	$f^{o}E$ (Mc/sec)	$f^{o}F1$ (Mc/sec)	$f^{o}F2$ (Mc/sec)	$f\ min$ (Mc/sec)	fEs (Mc/sec)	MUF 3000 km (Mc/sec)	M 3000 $F2$
January.....	219	335	301	2.88	4.24	5.23	0.90	3.8	15.40	2.97
February.....	215	318	279	2.80	4.26	5.22	0.88	3.4	15.97	3.05
March.....	219	307	268	2.73	4.26	5.28	0.87	3.2	16.35	3.10
April.....	221	301	250	2.72	4.27	5.45	0.85	2.8	17.60	3.17
May.....	220	288	242	2.52	4.12	5.10	0.78	2.8	16.40	3.23
June.....	227	288	244	2.51	4.12	4.64	0.70	3.3	15.30	3.25
July.....	219	286	244	2.53	4.11	4.70	0.80	3.2	15.40	3.25
August.....	219	289	249	2.65	4.21	4.75	0.71	3.2	15.58	3.25
September....	217	301	255	2.80	4.39	5.34	0.76	3.1	17.10	3.18
October.....	218	325	269	3.08	4.72	6.44	0.86	3.3	19.40	3.01
November....	224	338	281	3.08	4.76	7.11	0.80	3.9	20.80	2.93
December....	218	340	289	2.96	4.58	6.55	0.77	4.2	19.10	2.91

since then the program has been enlarged until the following geophysical phenomena are being continually recorded by the appropriate automatic equipment: (1) the three elements of the Earth's magnetic field by both a slow-run Eschenhagen and a movements in the east-west and north-south horizontal plane by the Wenner seismographs 9-N and 9-E and in the vertical direction by a Benioff vertical seismograph; (7) heights and ionic densities of the ionospheric regions in the Earth's upper atmosphere by

TABLE 7

PRELIMINARY MEAN HOURLY VALUES OF IONOSPHERIC DATA, WATHEROO MAGNETIC OBSERVATORY, 1945

120° east meridian time (h)	$h^{min}F1$ (km)	$h^{max}F2$ (km)	$h^{min}F2$ (km)	$f^{o}E$ (Mc/sec)	$f^{o}F1$ (Mc/sec)	$f^{o}F2$ (Mc/sec)	$f\,min$ (Mc/sec)	fEs (Mc/sec)	MUF 3000 km (Mc/sec)	M 3000 $F2$
00	...	338	258	...	...	4.23	...	3.3	12.3	2.93
01	...	329	253	...	...	4.16	...	3.3	12.4	2.96
02	...	321	246	...	...	4.00	...	3.2	12.0	3.01
03	...	319	245	...	...	3.82	...	3.1	11.5	3.00
04	...	315	242	...	...	3.63	...	2.9	11.0	3.03
05	...	307	242	...	...	3.49	...	2.9	10.7	3.07
06	...	291	238	...	...	3.89	...	2.9	12.5	3.18
07	...	279	250	2.02	...	5.03	0.63	3.3	16.6	3.30
08	...	285	278	2.58	...	5.86	0.75	3.6	19.3	3.28
09	222	298	297	2.90	4.24	6.36	0.82	3.9	20.4	3.21
10	219	307	309	3.10	4.45	6.82	0.88	3.8	21.6	3.12
11	216	314	311	3.20	4.52	7.22	0.90	3.9	22.4	3.12
12	215	316	306	3.23	4.56	7.43	0.91	4.1	22.9	3.10
13	217	316	304	3.23	4.53	7.62	0.91	4.0	23.5	3.10
14	221	313	298	3.16	4.43	7.66	0.89	3.9	23.8	3.13
15	223	304	288	3.00	4.27	7.56	0.85	3.9	24.1	3.17
16	...	294	269	2.70	...	7.14	0.77	3.7	22.9	3.23
17	...	286	248	2.22	...	6.67	0.69	3.5	21.7	3.27
18	...	288	234	...	...	6.02	...	3.1	19.4	3.25
19	...	295	229	...	...	5.26	...	2.8	16.5	3.17
20	...	313	235	...	...	4.75	...	2.7	14.4	3.06
21	...	325	247	...	...	4.45	...	2.8	13.2	2.99
22	...	334	256	...	...	4.32	...	2.8	12.4	2.94
23	...	342	259	...	...	4.26	...	3.0	12.3	2.91

fast-run la Cour set of variometers; (2) atmospheric potential-gradient by DTM recording unit 7; (3) positive and negative conductivity of the air by DTM unit 7; (4) earth-current voltages between four pairs of geographically oriented earthed electrodes by a Leeds and Northrup 12-point potentiometer recorder; (5) cosmic-ray radiation by CIW model C cosmic-ray meter 5; (6) seismic DTM ionospheric recorder 1; (8) radio field-intensities as received from four selected high-frequency distant radio stations by four recorder units; and (9) barometric pressure, temperature and humidity of the air, velocity and direction of winds, and hours of sunshine.

In addition, daily observations are made of the activity of the Sun's atmosphere with the Hale spectrohelioscope, of nuclei-counts, of

rainfall, of the barometric pressure, of the humidity of the air, and of the maximum and minimum temperatures of the air.

TABLE 8

RAINFALL AT WATHEROO MAGNETIC OBSERVATORY DURING 1945

Month	Monthly total (in.)	No. days	Average for 28 years (in.)
January	0.00	0	0.36
February	1.01	5	0.52
March	0.37	4	1.04
April	0.45	2	0.90
May	2.09	11	2.20
June	7.31	21	3.30
July	1.50	17	2.91
August	4.07	19	2.18
September	1.31	12	1.25
October	0.16	3	0.77
November	1.34	4	0.34
December	0.26	3	0.40
Totals	19.87	101	16.17

Magnetic base-lines for the Eschenhagen variometers were determined weekly by the use of CIW magnetometer 10 and earth-inductor 5, and scale-values were made electrically at least once a week. Scale-values for the la Cour variometers (*H* and *Z* only) were made once a month, but base-lines were not determined. A check of the orientations of the magnets in the Eschenhagen magnetograph was made in October 1945, and adjustments were made of all three variometers to correct for change in the magnetic meridian. Preliminary values for the annual changes from 1944.5 to 1945.5 as determined from the magnetograms for all days, referring the elements to the north-seeking end of the needle and reckoning east declination and north inclination as positive, are: declination, $-4'.3$; horizontal intensity, -38 gammas; vertical intensity, -15 gammas; inclination, $-1'.5$ (see table 1 for mean annual values). Table 9 summarizes the mean monthly scale-values for the two magnetographs for the calendar year 1945.

TABLE 9

SCALE-VALUES OF MAGNETOGRAPHS, HUANCAYO MAGNETIC OBSERVATORY, 1945

Month	Eschenhagen			la Cour	
	D ('/mm)	*H* (reduced to base-line) (γ/mm)	*Z* (means of daily values) (γ/mm)	*H* (γ/mm)	*Z* (γ/mm)
January	0.984	1.94	4.37	6.06	7.81
February	0.983	1.95	4.07*	6.07	8.00
March	0.984	1.95	4.13	6.18	7.94
April	0.986	1.95	4.14	6.79	7.94
May	0.984	1.96	4.16	6.48	8.09
June	0.985	1.96	4.18	6.25	7.95
July	0.986	1.95	4.19	6.24	8.29
August	†	1.94	4.25	6.24	9.23
September	0.986	1.94	4.27	6.09	9.26
October‡	0.982	1.93	4.16*	6.14	8.24
November	†	1.93	4.19*	6.19	8.40
December	0.980	1.94	4.22	6.22	7.61

* Mean value over several base-line shifts.

† Deflections for *D* off trace during August, and masked by *H* Helmholtz-coil during November.

‡ Orientation-tests were made during October.

Calibration observations for the potential-gradient and conductivity recorders were made weekly, and the potential-gradient reduction-factor was determined on August 13, 1945, and April 8, 1946, by comparisons with air-potentials measured on a near-by standardization plot. The preliminary mean values of the atmospheric-electric elements for the calendar year 1945 are shown in table 10.

The multifrequency ionospheric equipment, though it is now over eight years old and shows the wear and tear of its long service, was kept in operation by a systematic maintenance schedule and by a careful semiannual check-up, clean-up, and overhaul. Monthly calibrations of variable oscillator frequency were made, and semiannual complete calibrations of all units of the transmitter completed. New primary calibrations for all units were made, and new cams cut by the shop in Washington were installed in December 1945. The preliminary median hourly and median monthly values of the ionospheric data are shown in tables 11 and 12.

Four signal-intensity recorders were operated throughout the year, with practically no loss of record. Station WWV in Washington on frequencies of 15 megacycles and 10 megacycles was recorded on recorders 1 and 2, WVKF in Recife on recorder 3 until about the middle of December, when recording on CXA-19 of Montevideo was begun, and two different frequencies on NPN of Guam on recorder 4. In addition, special recordings on station HCJB in Quito were made for a week each at two different frequencies on recorder 4 in September 1945, utilizing only the active hours of that station.

Rainfall for the year 1945 was 25.04 inches, 4 inches less than the 24-year average of 29.03 inches. The dry season of 1945 was the driest and coldest in the history of the Observatory. No rain fell for nearly four months, and on 91 days a minimum temperature of less than 0° C was recorded. The maximum was 20°.25 C, in November. The lowest temperature for the year was −8°.7 C on July 1, 1945, and the lowest monthly mean minimum for

TABLE 10

PRELIMINARY MONTHLY MEAN VALUES OF ATMOSPHERIC-ELECTRIC ELEMENTS, HUANCAYO MAGNETIC OBSERVATORY, 1945

MONTH	No. SELECTED DAYS	POTENTIAL-GRADIENT		AIR-CONDUCTIVITY, UNIT 10^{-4} ESU			
		Reduction-factor	Value* (v/m)	λ_+	λ_-	$(\lambda_+ + \lambda_-)$	(λ_+ / λ_-)
January	2	....	55.7	3.50	3.70	7.20	0.95
February	1	....	51.4	4.20	4.20	8.40	1.00
March	1	. ..	47.5	3.60	3.53	7.13	1.02
April	11	1.20	52.2	4.00	3.90	7.90	1.03
May	10	....	52.1	3.73	4.01	7.74	0.93
June	5	1.20	44.7	3.85	4.29	8.14	0.90
July	6	....	52.6	3.80	4.25	8.05	0.90
August	2	1.10	53.2	3.50	3.70	7.20	0.95
September	2	. ..	47.2	4.20	4.60	8.80	0.91
October	2	....	55.5	3.67	3.70	7.37	0.99
November	6	....	43.5	4.18	4.20	8.38	1.00
December	2	....	83.4	3.46	3.19	6.65	1.08
Totals and means	50	1.16	53.2	3.81	3.94	7.75	0.97

* Using reduction-factor 1.15.

the year was −1°.99 C (the lowest on record for the Observatory) in May 1945. Table 13 gives the monthly rainfall and monthly mean maximum and minimum temperatures for 1945 as compared with the averages for 24 years.

In spite of an increase in the work of the Observatory and a decrease in personnel, scalings of traces and reduction of data were kept current until the last two months of the report-year. Maintenance of equipment suffered somewhat because of our short-handedness, but repairs were made and equipment adjusted as necessity demanded. Weekly broadcasts of three-hour-range *K*-indices and seismic data were kept up, and picked up by devoted amateurs who immediately transmitted the messages to the Department in Washington. Forty-eight seismic disturbances were thus reported by radio during the report-year. All monthly tabulations of magnetic, ionospheric, and field-intensity data were prepared as quickly as possible after the end of the month and sent by courier to Lima and by air-express to the Department in Washington; in addition, a United States cablegraphic message with an abstract of ionospheric data was transmitted through the Embassy in Lima. We continued to supply résumés of meteorological data to the Dirección General de Comunicaciones y Meteorología Aeronáutica in Lima and to the Huancayo military

TABLE 11

PRELIMINARY MEDIAN HOURLY VALUES OF IONOSPHERIC DATA, HUANCAYO MAGNETIC OBSERVATORY, 1945

75° west meridian time (h)	$h^{min}F1$ (km)	$h^{min}F2$ (km)	$f^{o}E$ (Mc/sec)	$f^{o}F1$ (Mc/sec)	$f^{o}F2$ (Mc/sec)	$f\ min$ (Mc/sec)	fEs (Mc/sec)	MUF 3000 km (Mc/sec)
00	...	230	...	...	6.2	...	...	19.4
01	...	235	...	...	6.0	...	...	17.8
02	...	240	...	...	5.1	...	...	15.3
03	...	250	...	...	4.1	...	...	13.0
04	...	250	...	...	3.3	...	...	10.5
05	...	265	...	...	2.9	...	...	8.8
06	...	260	1.6	...	4.2	1.2	2.6	13.3
07	...	240	2.5	...	7.1	1.2	3.3	23.0
08	230	285	2.9	4.4	8.2	1.7	5.4	25.1
09	220	320	...	4.5	8.8	1.8	5.6	23.3
10	215	340	...	4.7	8.3	1.9	5.6	21.5
11	210	355	...	4.7	7.8	2.0	5.5	19.8
12	210	365	...	4.7	7.7	2.0	5.6	19.3
13	200	355	...	4.6	8.0	2.0	5.5	20.5
14	210	330	...	4.6	8.3	2.0	5.5	21.8
15	210	300	...	4.4	8.7	1.8	5.5	23.1
16	...	230	2.8	...	9.1	1.7	5.5	24.2
17	...	250	2.3	...	9.2	1.3	3.7	24.3
18	...	275	1.2	...	9.1	...	...	24.5
19	...	300	...	...	8.6	...	...	23.2
20	...	295	...	...	8.1	...	...	22.6
21	...	280	...	...	8.1	...	...	22.5
22	...	245	...	...	7.9	...	...	21.7
23	...	235	...	...	7.8	...	...	21.6

TABLE 12

PRELIMINARY MEDIAN MONTHLY VALUES OF IONOSPHERIC DATA, HUANCAYO MAGNETIC OBSERVATORY, 1945

Month	$h^{min}F1$ (km)	$h^{min}F2$ (km)	$f^{o}E$ (Mc/sec)	$f^{o}F1$ (Mc/sec)	$f^{o}F2$ (Mc/sec)	$f\,min$ (Mc/sec)	fEs (Mc/sec)	MUF 3000 km (Mc/sec)
January	200	300	2.6	4.6	7.7	1.9	5.5	19.7
February	205	280	2.5	4.6	8.9	1.8	5.5	24.4
March	214	260	2.5	4.6	8.4	2.0	4.6	23.7
April	210	280	2.3	4.7	8.2	1.8	5.5	25.0
May	215	270	2.2	4.6	7.4	1.8	5.5	19.7
June	210	270	2.2	4.6	6.8	1.7	5.5	12.8
July	210	270	2.2	4.5	6.6	1.7	8.4	17.5
August	210	280	2.3	4.6	6.8	1.8	10.3	18.5
September	210	280	2.4	4.7	7.6	1.9	9.7	20.2
October	225	260	2.3	4.9	9.2	2.0	5.5	23.7
November	210	320	2.7	4.9	9.9	2.0	4.4	24.5
December	205	300	2.7	4.8	9.3	1.8	9.1	24.6
Medians	210	280	2.4	4.6	8.3	1.8	5.5	22.0

TABLE 13

MONTHLY MEAN METEOROLOGICAL ELEMENTS, HUANCAYO MAGNETIC OBSERVATORY, 1945, AND CORRESPONDING 24-YEAR MONTHLY MEANS, 1922–1945

Month	Total rainfall		Maximum temperatures		Minimum temperatures	
	1945 (in.)	24 years (in.)	1945 (°C)	24 years (°C)	1945 (°C)	24 years (°C)
January	4.97	4.97	17.40	18.60	6.16	6.93
February	3.46	4.25	17.71	18.21	6.25	6.93
March	4.48	4.46	17.17	18.13	6.51	6.46
April	1.53	2.05	18.80	18.85	2.74	4.66
May	0.16	1.12	19.75	19.36	−1.99	2.81
June	0.0	0.38	19.06	19.02	−1.29	1.63
July	0.0	0.29	17.95	18.89	−1.64	0.57
August	0.0	0.65	19.82	19.58	0.88	2.50
September	1.26	2.04	19.93	19.59	4.82	5.16
October	1.67	2.48	20.07	20.18	3.78	5.72
November	2.20	2.73	20.25	20.60	5.76	5.93
December	5.31	3.61	17.87	19.62	6.57	6.39

headquarters, and supplied other compilations of meteorological and magnetic data on request. The Instituto Geológico del Perú was also given monthly reports on earthquakes recorded at the Observatory.

Buildings, grounds, fences, power-plant, and water-supply system were carefully maintained in good condition and repaired as necessity demanded. One hundred eucalyptus trees were planted to replace those that died during the last dry season and to start trees in new places on the property.

Paul G. Ledig continued as Observer-in-Charge during the entire report-year. Mark W. Jones was absent on a vacation and official business trip to the United States during July, August, and September; Albert A. Giesecke, Jr., went on a similar trip in April to be absent over the end of the report-year. E. J. Chernosky continued as Observer until the middle of September, when he returned to the Department in Washington. T. Astete and E. Melgar continued as clerical assistants throughout the year, but V. Murga resigned in April 1946. Nevertheless, it has been possible through the whole-hearted endeavor of all members of the staff to keep the Observatory operating at high efficiency, and, except for the last two months, to keep all the work current.

From July to December 1945, owing to absences of personnel, it was possible for the Observatory to supply living-quarters for Mr. and Mrs. Harry Tschopik, of the Anthropological Division of the Smithsonian Institution, during which period Mr. Tschopik made a thorough social survey of the near-by native town of Sicaya. Franklin P. Ulrich, of the Seismological Division of the United States Coast and Geodetic Survey, was also a short-time visitor during the last days of April, when he and two members of the Instituto Geológico del Perú assisted in the annual check of the Observatory's seismological equipment. Dr. Marshall Hertig, of the United States Army Medical Corps, and two assistants spent several days at the Observatory in August, during which time they made moving pictures to illustrate the methods used in collecting phlebotomus flies, which are carriers of the "verruga" disease of the intermediate altitudes in Peru.

Acknowledgment is again gratefully made for the continued assistance of the United States Embassy in Lima in obtaining free entry from the Peruvian government for the supplies and equipment that come to the Observatory from Washington, and for the transmission of the monthly ionospheric message, as well as for kindness in supplying priorities for air-express shipments to the Department. It is a pleasure also to mention the many courtesies extended to the Observatory and members of its staff by the Peruvian government and its officials, and the whole-hearted friendliness shown by many other Peruvians of all classes.

College Observatory, Alaska. The College Observatory is located at the University of Alaska in the zone of maximum auroral activity, about 5 miles by road west of Fairbanks, in latitude 64° 51′.4 north, longitude 147° 49′.3 west, at about 381 meters (1250 feet) above sea-level. It has been operated by the Department in cooperation with the University of Alaska.

During July 1, 1944 to June 30, 1945, continuous records were maintained as follows: (1) three geomagnetic elements of declination, horizontal intensity, and vertical intensity; (2) rate of change of geomagnetic horizontal intensity; (3) height- and penetration-frequencies of the ionospheric regions; (4) electric field-strength of radio waves from selected high-frequency broadcasting stations in the United States, England, and Japan; (5) direction of arrival and instantaneous field-strength of high-frequency radio signals. During all or part of the year seismographs were operated for the United States Coast and Geodetic Survey and also solar-radiation measuring instruments for the United States Weather Bureau. Preliminary analyses of seismograms were completed at College, and with records of solar radiation were transmitted to the respective bureaus.

Adequate control-observations and standardizations for all instruments were made to assure reliability of the resulting data.

The la Cour magnetograph functioned satisfactorily. Control-observations were made several times monthly, until the last few months, when unusually long periods of magnetic disturbance permitted observations only once in two months. Reductions of the records were kept current. At weekly intervals *K*-index figures were telegraphed to the Department, and the records, tabulations, and reductions were forwarded monthly. Scale-values have differed little since installation, those for the year 1944 being 5′.2/mm for declination, 18.2γ/mm for horizontal intensity, and 27.1γ/mm for vertical intensity. The preliminary mean values for all days of the year 1945, referring the elements to the north-seeking end of the needle and reckoning east declination and north inclination as positive, are: declination, +29° 41′.8; horizontal intensity, 12597γ; vertical intensity, +55360γ.

Operation of the *H*-fluxmeter was essentially maintained during the year, although the instrument continued to give some trouble from an operating standpoint. Reports giving summaries of the instrumental constants and summaries of the largest variations during each month were forwarded to the Department at the end of each month.

Ionospheric observations were made continuously, and summaries of the results were transmitted daily. Reductions and calibrations were sent to the Department at monthly intervals. Information on local propagation conditions was furnished the Air Corps and other agencies in and near Fairbanks. The preliminary results for median hourly values of the ionospheric data for 1945 are shown in table 14.

The four signal-intensity recorders functioned without interruption. Certain modifications in station schedules made it necessary to utilize other stations for satisfactory recording, and these changes were appropriately noted on the tabulations for each month. In general there has been no difference in the character of received signals as compared with previous reports.

Observations of direction of arrival of high-frequency radio signals were made by means of the Navy Model DAB-3 direction-finder at half-hourly intervals. Observations were made manually and summaries of results were forwarded weekly for analysis. Close cooperation with the Air Corps and with civilian agencies for use of the direction-finder during emergencies was maintained.

In addition to current routine reports, Seaton and his colleagues of the temporary staff prepared discussions and analyses of data on the following subjects: (1) magnetic observations at College (Wilder)—(*a*) July through August 1943, and (*b*) for 1944—giving tabulations of data and magnetic activity, graphical summaries, and comparisons with results of previous years; (2) summary of ionospheric results at College for 1945 (Cashen and Seaton), presenting graphical summaries of ionospheric characteristics and showing a continued increase in electron-concentration with increasing solar activity; (3) magnetic and ionospheric characteristics during disturbed intervals (Malich), in which study of selected, abrupt magnetic-ionospheric disturbances showed that there was close detailed connection between some magnetic and ionospheric changes, and that abrupt magnetic disturbances generally preceded ionospheric changes by varying times ranging to 5 minutes or more, with time-interval and rate of change of disturbance suggesting a real rather than an apparent effect; (4) direction-finder results at College for September through October 1945 (Kowalak, Cashen, and Seaton), showing that a systematic deviation in direction of arrival of radio signals occurs with change of beam antennas at the transmitter; (5) signal-intensity measurements at College for 1945 (Wolff and St. Amand), presenting tabular and graphical summaries of data and comparison of earlier work; (6) direction-finder studies at College (Seaton), giving solution for the direction-finder-error problem in terms of horizontal ion-gradient and of lateral tilt of ionospheric structure when the error arises from deviation of the sky wave; (7) description of a matching network for use with standard signal-generator (Seaton), discussing the problem of matching the signal-generator into the receiver load during cali-

bration of the receiver and describing a simple network to attain the desired result; (8) tests of Army emergency transmitter in Alaska, January to February 1945 (Wolff), describing results of tests of an Army-type emergency transmitter during cold weather and coordinating results with propagation conditions of the ionosphere. Of these, the solution of the sky-wave-error problem in direction-finding is perhaps the outstanding contribution of the group during the report-year. E. F. George also prepared a paper on frequency of collision of electrons with air molecules which was submitted to the Institute of Radio Engineers for publication.

During May 1946, Seaton spent some ten days in Washington, D. C., to study improved techniques for ionospheric apparatus and to confer regarding the shifting, on July 1, 1946, of complete responsibility for operations at College from the Department to the University of Alaska under contract with the newly formed Central Radio Propagation Laboratory of the National Bureau of Standards. This visit also permitted him to take part in hearings of May 10 and 11, 1946, before the Committee on Territories of the United States House of Representatives on the bill [1] for the establishment of a Geophysical Institute at College, in the planning

TABLE 14

PRELIMINARY MEDIAN HOURLY VALUES OF IONOSPHERIC DATA, COLLEGE OBSERVATORY, ALASKA, 1945

150° west meridian time (h)	$h^{min}F1$ (km)	$h^{min}F2$ (km)	$f^{o}E$ (Mc/sec)	$f^{o}F1$ (Mc/sec)	$f^{o}F2$ (Mc/sec)	$f\ min$ (Mc/sec)
00	...	298	1.0	...	2.4	0.8
01	...	308	1.1	...	2.5	0.8
02	260	322	1.3	2.8	2.6	0.8
03	258	331	1.5	3.0	2.7	0.8
04	262	339	1.8	3.1	2.9	0.8
05	246	339	1.7	3.3	3.0	0.9
06	232	367	2.0	3.4	3.3	1.0
07	225	335	2.2	3.6	3.6	1.1
08	219	332	2.2	3.7	4.0	1.1
09	217	334	2.3	3.7	4.6	1.4
10	213	329	2.5	3.9	5.1	1.4
11	215	330	2.5	3.9	5.4	1.4
12	219	324	2.6	4.0	5.6	1.4
13	219	318	2.5	3.9	5.6	1.3
14	220	312	2.4	3.9	5.6	1.2
15	225	297	2.2	3.9	5.3	1.3
16	227	278	2.1	3.7	5.0	1.3
17	231	273	1.8	3.7	4.6	1.1
18	237	260	1.8	3.6	4.1	1.1
19	238	258	1.6	3.2	3.8	0.9
20	247	264	1.3	3.0	3.3	0.9
21	...	270	1.3	...	3.0	0.8
22	...	273	1.1	...	2.7	0.8
23	...	287	1.0	...	2.6	0.7

[1] The bill (79th Congress, Second Session, H.R. 6486 with Report No. 2142) to authorize an appropriation for the establishment of a Geophysical Institute at the University of Alaska was passed by the United States Senate July 17, 1946, and was later duly signed by President Truman.

for which he had already given the University considerable assistance.

In general, the year's work re-emphasizes the desirability of continuing research of the sort undertaken. It is desirable to encourage other agencies to take over the routine phases of arctic research, reserving to agencies such as the Department and the Geophysical Institute—when realized—problems requiring pioneering.

The conclusion of another year in the cooperative program of the University of Alaska and the Department affords a satisfactory example of successful collaboration in the complex fields covered by observational records, experiments, and discussion. The liaison between the University's authorities and the Department was maintained most satisfactorily.

Cooperation with Other Observatories

Cheltenham and Tucson magnetic observatories of United States Coast and Geodetic Survey (United States). The cooperative program at Cheltenham in maintaining absolute magnetic standards and automatic records of cosmic-ray intensity (Observers-in-Charge, J. Hershberger and W. E. Wiles), and that at Tucson in registrations of atmospheric potential-gradient and of positive and negative air-conductivities (Observer-in-Charge, J. H. Nelson), were continued as during the preceding report-year. Because of illness on the staff at Tucson, the reductions of the atmospheric-electric records for the year 1945 are not yet completed and the usual summaries of results are not available.

Apia (Western Samoa), Hermanus (South Africa), Godhavn (Greenland), Christchurch (New Zealand), Mauritius, and Teoloyucan (Mexico) observatories. The magnetic and other programs, as indicated in last year's report, were continued at these stations. The effective cooperation of those in charge of these observatories and of their staffs have made for good progress in geomagnetic sciences.

Ivigtut Magnetic Observatory (Greenland). With the termination of the war, the program carried on at this temporary station during the war years was discontinued on July 16, 1945. The Department is greatly indebted to Manager S. O. Corp of the Ivigtut Cryolite Mines for generosity in so long continuing this useful emergency program.

PUBLICATIONS

The report-year was marked by completion of master-copies and offset publication of the last two of the thirteen volumes in the series "Scientific Results of Cruise VII of the *Carnegie* during 1928–1929, under Command of Captain J. P. Ault." (For details regarding these see Year Book No. 44, 1944–1945, pp. 52–53.) It was possible to add to the reports and discussions noted in Year Book No. 44 for volume Oceanography III two interpretative papers by Torreson, namely, "The ratio of positive to negative conductivity on Cruise VII, and its variation with potential-gradient" and "Interesting aspects of the air-earth current as derived from atmospheric-electric data of Cruise VII of the *Carnegie*." In the first paper it was shown that for quite small changes in positive potential-gradient, say in going from 120 to 180 volts, there was an appreciable "electrode-effect" which increased the ratio of positive to negative conductivity, or positive to negative small-ion concentration, by about 10 per cent. Concordant results were obtained for both Atlantic and Pacific oceans. The second paper was concerned with certain low values of air-earth current-density derived from unusual values of conductivity and potential-gradient encountered on three separate occasions during Cruise VII. It was suggested that low values of air-earth current-density prevail when condensation-nuclei, or other disturbing elements,

are present in the lower atmosphere in a layer which may on one occasion be only a few meters thick but on another may be as much as a few kilometers thick. Further, the layer of disturbing material may be hundreds of miles in horizontal extent, and passage from an undisturbed region into a disturbed region may be very abrupt, requiring but a few minutes, a fact which suggests that the layer of disturbed material has a "front."

In October 1945, final preparation of master-copy was begun for the publication of magnetic results from Watheroo Observatory. Text, illustrations, and tables of data already prepared by H. F. Johnston for the years 1919 to 1935 were examined and edited. The manuscript was enlarged by additional material describing other work than the magnetic. The tables were revised and extended, and section A of volume VII (1128 pages) of the "Researches" (Carnegie Inst. Wash. Pub. 175) was transmitted in June 1946 to the Office of Publications of the Institution. Volume VII-A includes, besides description of the observatory, review of magnetic activity and storms, complete tabulations of magnetic data, reproductions of disturbed-day magnetograms, graphs of diurnal variation, and interrelation hodograms for the years 1919 to 1935. In January 1946 work was begun on volume VII-B (about 600 pages), to include results from Watheroo during 1936 to 1944, and this was about one-half completed by the end of June, with the manuscript ready for electromatic typing, all miscellaneous tables prepared and half of them typed, and all tables of hourly mean values ready for offset printing. Tables of diurnal variation and noncyclic change remain to be prepared.

The preparation of the above material was in charge of Torreson, with the efficient assistance, in editing and preparation of master-copy, of Mrs. Crow (until February 15, 1946) and of Miss Walburn (from February 25, 1946)—the two last named being of the Office of Publications of the Institution. Green and Hendrix prepared the numerous photographs and drawings required for illustrating the volumes.

Large accumulations of data and discussions, some in part already processed for offset printing, remain to be published. This work has been delayed unduly by reason of the operations and loss of the *Carnegie* and of the five-year interruption of the war. This material may be roughly summarized as to subject, period, and estimated number of pages as follows:

Subject	Period	Est. no. pages
Observatory series		
A. Magnetic data:		
Watheroo	1936–1944	600
Huancayo	1922–1935	1000
Huancayo	1936–1944	600
B. Atmospheric electricity:		
Watheroo	1924–1934	500
Huancayo	1924–1934	500
Tucson	1931–1941	500
C. Earth-currents:		
Watheroo	1926–1946	600
Huancayo	1927–1946	600
Tucson	1935–1946	400
D. Cosmic rays:		
Huancayo	1936–1946	300
Christchurch	1936–1946	300
Godhavn	1938–1948	300
Cheltenham	1936–1946	300
E. Ionospheric data:		
Watheroo	1935–1946	500
Huancayo	1935–1946	500
Survey and special studies series		
F. Land and ocean magnetic observations	1927–1946	850
G. Magnetic researches and discussions		2000

It is expected that the majority of the volumes listed above will be printed by the offset method for general distribution, and that others consisting largely of graphs and extended tabulations, for which only limited distribution is needed, will be reproduced in microfilm. Complete publication, making the results of observation and compilation so generously supported by the Institution for many years available for ready circulation to investigators and scholars in all parts of the world, is a paramount responsibility. It is to be noted that item B contemplates publishing results and discussions to cover one sunspot-cycle only, although the atmospheric-electric program at each observatory has been continuous from the beginning of operations.

INSTRUMENT-SHOP

The Instrument-Shop looked after the construction and maintenance of instruments and operation of the cyclotron. Approximately two-thirds of the time of the staff involved war contracts, the remainder being used for construction of new equipment and experimental apparatus, repairs and improvements to instruments and apparatus, buildings and grounds, and miscellaneous items.

A large portion of the other-than-contractual work involved replacement parts for ionospheric, atmospheric-electric, and anemographic apparatuses at Watheroo, Huancayo, and College observatories. Minor repairs and modifications were made to several magnetometers and inductors, ion-counters, and ionization-chambers. From May 1946, the establishment of the new Derwood Experimental Laboratory and removal to its site of buildings, equipment, and supplies from the Kensington Ionospheric Station placed a heavy burden on the shop (see p. 54). Some improvements and modifications were made to the justifying typewriter in order to obtain a more compact design.

The woodworking shop looked after packing and shipping of equipment and supplies for contracts and for annual requisitions, as well as construction in, and minor repairs to, all buildings at Washington and Kensington.

MISCELLANEOUS ACTIVITIES

Members of the staff participated actively in scientific meetings, conferences, and organizations; many served as officers and on special committees. Contacts were maintained with geophysical organizations and geophysicists abroad and in the United States. Many activities related to concluding aspects of the war effort and conferences with cooperating observatories, organizations, and individuals in the United States, Canada, Europe, the Union of Soviet Socialist Republics, Australasia, India, and China.

Besides papers and reports noted above and in the appended bibliography, some thirty scientific and popular lectures and radio broadcasts were presented by Berkner, Cowie, Duffin, Fleming, Gish, Hafstad, Harradon, Tuve, and Wells before technical societies, universities, academies, governmental bureaus, and clubs. The subjects related to radio communication and the ionosphere and interpretations, nuclear physics and the cyclotron and its biophysical and medical applications, radium protection, problems in nonlinear mechanics and networks, volcanism, recent progress and aspects of geomagnetism and applications to defense, the radio proximity fuze. These lectures were widespread geo-

graphically, being given before organizations in England, Canada (New Brunswick and Quebec), and United States (District of Columbia, Maryland, Massachusetts, Michigan, New York, North Carolina, and Texas).

Tuve and G. Breit (formerly a Research Associate of the Institution) received Fellow Awards for 1945 in the Institute of Radio Engineers "for pioneering in the experimental probing of the ionosphere and giving to the world the first publication of the experimental proof of the existence of the ionosphere; and for having initiated at an early date the pulse method of probing by reflection which is the basis of modern radar."

Fleming was elected March 16, 1946, a Member of the Norwegian Academy of Sciences in Oslo in its Section of Mathematics and Natural Sciences.

In August 1946, Wells was appointed a member of the Technical Committee on Radio Wave Propagation and Utilization of the Institute of Radio Engineers.

Berkner was appointed May 10, 1946, a member of the Special Subcommittee on the Upper Atmosphere of the Committee on Aerodynamics of the National Advisory Committee for Aeronautics.

Gish was reappointed by the National Advisory Committee for Aeronautics in February 1946 as a member of its Subcommittee on Lightning Hazards to Aircraft.

The Department was awarded on December 10, 1945, the Naval Ordnance Development Award (given in recognition of distinguished service to the research and development of naval ordnance) for outstanding performance in connection with the research and development of proximity fuzes and related components, and also for intensive studies of the relation of the Earth's magnetic field to ordnance devices. Certificates of exceptional service to naval ordnance and lapel emblems were awarded to the Director and 12 leading members of the staff, and certificates of distinguished service and the lapel emblems to all other members of the Department.

Library. The end of the war in Europe, shortly before the opening of the report-year, gradually made for important changes in the international situation with regard to availability of foreign scientific books and journals. The lifting of postal restrictions, except for Germany and Japan, permitted the exchange of journals and printed material issued during and since the cessation of hostilities, making possible the completion of our series of several of the leading scientific periodicals and year books.

With regard to domestic periodicals, there was a notable increase in articles in all branches of geophysics. This is so partly because much material classified as restricted or secret during the war has now been released for publication, and partly because of the return of scientists from war-research to prewar positions. Scientific meetings, discouraged during the war but now being held in increasing numbers, have been characterized by large attendance and crowded programs, indicating rapid progress toward normal conditions.

The number of accessions during the report-year was 430, bringing the total number of books and pamphlets accessioned on June 30, 1946, to 28,385. The practice adopted in the past of cataloguing all articles in current scientific journals of interest in connection with the work of the Department was continued, thus assuring ready reference to material in the Library which otherwise might not be easily found.

Librarian Harradon continued as co-editor of the *Journal of Terrestrial Magnetism and Atmospheric Electricity,* giving attention particularly to foreign contribu-

tions, preparation of notes, and the compilation of annotated bibliographies of recent publications on cosmic and terrestrial magnetism and electricity. The increased number of titles together with a more liberal policy with regard to their selection greatly enhanced the usefulness of the bibliography.

The Librarian also continued as Secretary of the Section of Meteorology of the American Geophysical Union and Chairman of the Committee on Statutes and By-Laws of the Union. He also gave assistance from time to time in the preparation of the bibliographical matter and supplied material for the *Transactions* of the Union.

The list of publications by members of the Department on December 31, 1945 showed a total of 2348. During the latter part of the report-year, the large quantity of reprints which had accumulated during the war was sent to all countries with which postal relations had been re-established. This work was done under Dove's supervision with the aid of Mrs. Hopkins and Simkins, of the temporary staff.

The facilities of the Library have been extended to investigators from universities and government bureaus and particularly to those still working on contracts of the Army and Navy. Information on a wide range of subjects was supplied in response to inquiries from various sources. Cordial relations and interlibrary loans were maintained with other libraries, particularly the Library of Congress.

Dove continued as Secretary to the Director and was also designated as Assistant Librarian from January 1, 1946. He remained in charge of the general correspondence files and the storage and distribution of reprints. He typed many reports and manuscripts and gave much assistance in proofreading.

Office administration. Many of the war contracts on which the Department has been engaged were continued following the cessation of hostilities, upon request of the bureaus concerned, because of the peacetime applications of these projects. Much of the time of the staff assigned to Administrative Assistant M. B. Smith was again given to contractual matters. Toward the end of the report-year a large amount of time was given to the termination of some of the contracts and short-time extensions of others. Assistance was given in connection with matters concerned with the National Academy of Sciences, the International Council of Scientific Unions, and the International Union of Geodesy and Geophysics. Many matters dealing with selection, purchase, and development of the site for the Derwood Experimental Laboratory were looked after, in addition to the routine administrative work of the Department. Moats and Singer and Miss Dermody of the regular staff, and the temporary employees assigned to the Administrative Assistant, made possible by their constructive and faithful assistance the accomplishment of the unusually heavy administrative demands.

The many details of wartime shipments, inventories, statements of time and costs of work, preparation of reports and manuscripts, and secretarial work for the Director were completed by Capello and Dove. Charts, diagrams, and illustrations for many special reports and publications were prepared by Hendrix, who with J. W. Green also did much necessary photographic work. Filing and arranging of field-records were done by Miss Balsam, who with Capello maintained the catalogues of photographs and films, and index-albums of prints.

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SPECIAL PUBLICATIONS

Scientific results of Cruise VII of the *Carnegie* during 1928–1929, under command of Captain J. P. Ault:

Oceanography—I-B. Observations and results in physical oceanography. Oceanographical and tabular summaries. By J. A. Fleming, H. U. Sverdrup, C. C. Ennis, S. L. Seaton, and W. C. Hendrix. Carnegie Inst. Wash. Pub. 545, iv + 315 pp., 254 figs. (1945).

Oceanography—III. Ocean atmospheric-electric results. By O. W. Torreson, O. H. Gish, W. C. Parkinson, and G. R. Wait. Carnegie Inst. Wash. Pub. 568, vii + 178 pp., 42 figs. (1946).

Oceanography—IV. The work of the *Carnegie* and suggestions for future scientific cruises. By J. P. Ault, J. H. Paul, J. A. Fleming, E. G. Moberg, S. E. Forbush, E. S. Shepherd, and R. M. Crow. Carnegie Inst. Wash. Pub. 571, v + 111 pp., 61 figs. (1946).

SPECIAL PROJECTS: TERRESTRIAL SCIENCES

COMMITTEE ON COORDINATION OF COSMIC-RAY INVESTIGATIONS. *Progress report*[1] *for the period July 1945 to June 1946.* (For previous reports see Year Books Nos. 32 to 44.)

As has been indicated in the annual reports of the Committee from 1940, relatively large progress could not be made during the war years. In view of the fundamental importance of this branch of physics, this limited progress, as one would expect, has raised more questions than answers. With the cessation of hostilities and the eventual reconversion from wartime to peacetime efforts of the investigators in the field of cosmic radiation, it may well be expected that research will be vigorously resumed, particularly in the investigation of high-energy radiations to which natural cosmic radiation gives an immediate avenue of approach. Thereby we may expect to learn basic facts by which to check theories of nuclear forces and interactions between radiation and matter.

The programs, supported in whole or in part by the Committee, of groups at the Department of Terrestrial Magnetism of the Carnegie Institution, at the Bartol Research Foundation of the Franklin Institute, and at New York University, so far as emergency and reconversion conditions permitted, have gone forward during the year ended June 30, 1946, as is evidenced in the appended reports by Forbush and Lange, Johnson, and Korff. As will be noted from the first of these, the automatic recordings at observatories listed in last year's report (see Year Book No. 44, p. 59, and earlier Year Books) have been successfully maintained during the year in spite of difficulties occasioned by limitations of supplies and personnel, now perhaps even greater than in the previous war years.

Advice as to prospective completion of work under way, from the other groups who have so long and ably taken part in the researches as listed in the annual reports of the Committee since 1932, is summarized below.

For the California Institute of Technology, Dr. Millikan says:

> We are already started vigorously on the program of *counter-registered flights* to the top of the atmosphere in the area between Oklahoma City and Saskatoon. Such flights are exceedingly vital because it is in this latitude range that our predictions locate the incoming hydrogen rays, which is the last and most critical latitude in which our theory of the origin of cosmic rays has not yet been carefully tested. We shall need the whole of the balance now available to complete this program. The needed balloons are better than the prewar balloons, but they cost two or three times as much as the old ones. Further, we shall not start on this expedition until we have finished satisfactorily the job which we are now on, which is "improving the reliability of counters" above that of those that have been available in the past. . . . It may be necessary to postpone the flights until the summer of 1947, for the winter winds and other conditions introduce considerable hazards which are not met with in the more stable conditions in summer and fall.

For the group which was also originally at California Institute of Technology, Professor Carl E. Nielsen reports that he has been appointed to the faculty of the University of Denver and hopes soon, there-

[1] For a statement on formation, purposes, and policies of the Committee see Year Book No. 38 (1938–1939), pp. 335–349.

fore, to do more cosmic-ray research on Mount Evans, using the cloud-chamber and magnet provided at California by the Committee. He thinks of getting more data on the mass of the meson and of studying further the relative numbers of electrons, mesons, and protons at various elevations. Dr. Nielsen further states that during the first half of 1946:

After various delays, including the interruption of Frost's work by his induction into the armed forces, an experiment was finally set up for getting the ionization-curve for slow electrons needed before the analysis of the meson-mass data obtained in 1942 [see Year Book No. 42, pp. 62, 68–69; No. 41, p. 102] can be properly concluded. . . . A somewhat novel arrangement is used involving photographing the tracks in a direction perpendicular to the magnetic field. This makes it easy to get the electrons into the cloud-chamber since they spiral around the lines of force, and it permits much more accurate measurements of momentum of slow electrons than does the conventional set-up. The few pictures already taken this way look very promising.

Professor Walter H. Nielsen, of Duke University, in view of the reorganization of his Department of Physics and a large number of problems associated with reconversion as well as his inability to lay the groundwork for a continuation of his proposed cosmic-ray investigations, finds that he cannot take up at any time soon the research for which the Committee made a small grant some years ago. Because of the necessary postponement of any work by Dr. Nielsen, and following his suggestion, the amount of the grant was reverted to the general funds of the Committee.

The study on motion of cosmic-ray particles in the Earth's magnetic field by Professor M. S. Vallarta remains at a standstill, as stated in previous reports, because of limitations imposed by the war on the use of the differential analyzer at the Massachusetts Institute of Technology, which is required in his work.

The cosmic-ray data obtained at the Teoloyucan station (elevation 2285 meters) in Mexico exhibit certain unexplained anomalous features when compared with the records of cosmic radiation at the four other stations; the data seem to disagree with the accepted hypothesis of variation with geomagnetic latitude. The Committee was happy, therefore, to be advised by Professor Amadore Cobas, who has done considerable cosmic-ray research, that the Faculty of the Natural Sciences of the University of Puerto Rico would like to provide for the installation of a CIW meter at Rio Piedras. Rio Piedras is practically in the same geomagnetic latitude as Teoloyucan, but at sea-level, and records obtained there for a year or two, while the program at the Mexican station is continued, should confirm the anomaly, or, if not, should provide means of explaining it. The University's invitation was accepted and arrangements were made by transfer of a meter, not in immediate use at the University of Chicago, to Washington for minor improvements before making shipment to Puerto Rico. The personnel of the Department of Physics, of which Professor Cobas is the head, will install and operate the meter, transmit the data to Washington, and probably undertake some discussion thereof.

Plans were considered by Dr. T. H. Johnson for further use of the high-pressure cloud-chamber constructed, in part from funds of the Carnegie Institution of Washington, after his design and supervision, at the Bartol Research Foundation of the Franklin Institute (see Year Book No. 39, p. 126, and subsequent annual reports of the Committee). These suggestions involve the use of the chamber for special research in connection with a betatron. Since the X-rays from a betatron

have sufficient energy to produce mesons, which heretofore could only be observed infrequently in cosmic radiation, the betatron offers a unique opportunity for studying the characteristics of mesons; use of the pressure cloud-chamber would be of great advantage as compared with the ordinary cloud-chamber in this as in the case of cosmic-ray tracks. The chance of observing meson-decay is about one thousand times greater in the high-pressure chamber than in the ordinary cloud-chamber, and this is ample justification for the proposed use of the high-pressure chamber in connection with a betatron.

In a general summary of the present status of the fields of cosmic-ray research, submitted to the Committee through President Bush, Dr. Johnson, who has so long and ably collaborated with us, believes that "a field bristling with unsolved problems now ripe for attack with good promise of successful and important results . . . cannot but enlist men to carry on a program on as large scale and at as fast a pace as would be economical." He is "impressed with certain important advantages of a research institute over a university laboratory for cosmic-ray investigations. In the first place much of the work is difficult to adjust to an academic schedule, and secondly, although the university has advantages of providing an influx of young minds and of stimulating comprehensive analyses of research results through lectures on a graduate level, yet these advantages may also be realized in a research institute if the group is of sufficient size, and if provision is made to have a rotation of outstanding theoretical physicists attached to the group at intervals on a consulting basis."

Dr. Johnson offers also the following comments:

The most promising experimental studies to be made concern the nature and energy-distribution of the primary cosmic rays and the genetics of the secondaries produced in matter by them, especially the role played by the meson. . . . Mesons were first invoked to explain nuclear forces, but almost simultaneously particles of similar properties were discovered as the main component of the cosmic radiation at sea-level. Attempts by Nordheim, Oppenheimer, Heisenberg, and others to form an over-all picture of the cosmic radiation consistent with the available experimental evidence, including the meson interpretation of nuclear forces, have come to the view that the primary cosmic rays are protons (consistent with east-west measurements in 1933–36 and the recent work of Schein, Jesse, and Wollan), and that these produce in the high atmosphere two kinds of mesons, one of short decay-period and another of longer decay-period. The former disintegrate almost at their point of production giving rise to the electrons and gamma rays of the soft component while the latter form the penetrating component observed at sea-level and below. In the absorption of mesons the electrostatic interaction between its charge and the electrons of matter leads to the normal ionization, but the "magnetic-spin" interaction seems to be important in production of bursts, especially at great depths where the average energy is higher. The theories seem to explain most of the observations, but in many points the evidence is scant, and there are many unexplained phenomena such as cloud-chamber pictures of several hundred soft electrons emitted from a single point and definitely not to be explained by the usual cascade theory. The theory is also vague in accounting for meson showers, and the presence of high-energy protons at sea-level. To tie the whole thing down will require much careful measurement. The following are needed: Statistics on the probability of decay of mesons as a function of sign of charge, remaining energy and previous history in matter; measurements on the distribution in angle of mesons scattered in matter as a function of their energy to determine the law of force between mesons and nuclei; measurements of the angles and energies of mesons

produced in showers to throw light on the process of production of these particles; statistics on the frequency of meson production and decay at several altitudes and depths below sea-level to find out what kinds of rays are producing them and whether there is really more than one kind of meson; measurements of the mass and statistics regarding the distribution of masses; visualization of the previously postulated processes taking place in the gas of the high-pressure cloud-chamber; statistics on the angles and energies of electrons kicked out of atoms by mesons; more information on the energy-distribution of the primary rays of the type that can be obtained by the balloon techniques. . . . Techniques are already available for most of these studies. The large low-pressure cloud-chamber built by Carnegie funds at the Bartol Foundation should be continued in operation, and work with the new high-pressure cloud-chamber first put into operation by Shutt, de Benedetti, and Johnson in 1942 should be used in its present form, and this principle should be further developed. Other expeditions will be required for cloud-chamber studies at high altitudes and for balloon-flights in several latitudes. Underground studies should also be made with cloud-chambers and counter-tube arrangements.

The balance ($17,500) of the funds so generously allotted for the activities of the Committee and eminent cosmic-ray investigators since its formation in 1932 is sufficient to provide for the completion of data over one sunspot-cycle, as originally contemplated by the Committee, at each of the stations where CIW model-C cosmic-ray meters have been installed. The only exception is the station at Puerto Rico, for which a meter is now being prepared for shipment. At this station it is desired only to obtain data for one or two years to clarify apparent anomalies observed at the station at Teoloyucan, Mexico, in approximately the same geographic and geomagnetic latitude, as stated above. As regards balances for individual investigators, they are sufficient to meet needs for final expenses and reports on researches planned which have had the approval and support of the Committee for some years. These approved projects, for which progress has been reported annually (see Year Books Nos. 32 to 44), all nearing completion, are as follows:

(*a*) Cosmic-ray studies with 24-inch high-pressure cloud-chamber to obtain additional information on the character and behavior of the meson, using improved arrangements of lead absorbing and scattering plates (Dr. T. H. Johnson).

(*b*) Measurements on meson-production layer and correlation with meteorology (Dr. S. A. Korff).

(*c*) Counter-registered flights to the high atmosphere in range of latitude between Oklahoma City and Saskatoon to test earlier hypothesis (see Year Book No. 43, pp. 56–60) on predictions of incoming hydrogen rays—the last and most critical range of latitude in the theory of origin of cosmic rays—and improvement of reliability of counters (Dr. R. A. Millikan).

(*d*) Further cosmic-ray research and discussions of accumulated observations and photographs on Mount Evans (Dr. Carl E. Nielsen).

(*e*) Investigation of the motion of cosmic-ray particles in the magnetic field of the Earth, the theory of magnetic storms, and related problems utilizing modern automatic calculating techniques (Dr. M. S. Vallarta).

(*f*) Continuation of cosmic-ray automatic recording with CIW model-C meters in order to complete data for a period of at least one sunspot-cycle at Cheltenham (United States), Christchurch (New Zealand), Godhavn (Greenland), Huancayo (Peru), and Teoloyucan (Mexico), and of similar recording, under the skilled supervision of Professor Cobas (see Year Book No. 44, p. 59), for one or two years at Rio Piedras (Puerto Rico), all for sound statistical treatment as regards both

regular and irregular variations of cosmic radiation with short and long periods of time, with geographic distribution, and with other cosmic (especially solar) phenomena (S. E. Forbush and Miss I. Lange and cooperating organizations).

With the retirement from active service in the Institution on or before June 30, 1946, of all three members of the Committee, the Committee recommended to President Bush that, effective July 1, 1946, (1) administration of its then uncompleted activities be made the responsibility of the Department of Terrestrial Magnetism of the Institution, and (2) funds still available from past appropriations be set aside, in accordance with the approved projects above listed, for disbursement by that Department through its Director. The President approved these recommendations.

This is, therefore, the fourteenth and final annual report of the Committee; future reports on the completion of projects sponsored by it will be made through the Director of the Department of Terrestrial Magnetism of the Institution.

In conclusion, the Committee expresses grateful appreciation for the privileges it has enjoyed since 1932: the association with many eminent investigators who have always selflessly striven for progress; the cooperation of many scientific organizations which have provided without charge observing facilities and trained personnel to obtain continuous records with the CIW cosmic-ray meters; and the large financial support given by the Carnegie Corporation and the Carnegie Institution of Washington and sponsored by Presidents Merriam and Bush. Specific references to these are given in the reports published annually in Year Books Nos. 32 to 45 of the Institution.

W. S. Adams
J. A. Fleming, *Chairman*
F. E. Wright

Statistical Investigation of Cosmic-Ray Variations at Department of Terrestrial Magnetism

S. E. Forbush and Isabelle Lange

Instruments. Operation of the Carnegie Institution's precision cosmic-ray meters was continued at the following stations: Cheltenham (Maryland, United States) Magnetic Observatory of the United States Coast and Geodetic Survey, meter C-1, John Hershberger and William E. Wiles in charge; Huancayo (Peru) Magnetic Observatory of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, meter C-2, P. G. Ledig in charge; National Astronomical Observatory of Mexico at Teoloyucan (D. F., Mexico), meter C-4, Dr. Joaquin Gallo in charge; Amberley Branch of the Christchurch (New Zealand) Magnetic Observatory of the Department of Scientific and Industrial Research, meter C-5, J. W. Beagley, succeeded December 1945 by V. B. Gerard, in charge; Godhavn (Greenland) Magnetic Observatory of the Danish Meteorological Institute, meter C-6, K. Thiesen, succeeded October 1945 by Mr. Lundbak, in charge.

Reduction of data. Because of the Department's participation in war problems and demands incident to reconversion, it was not possible to effect the scaling, reduction, and analysis of the large mass of cosmic-ray data which accumulated during the war. Considerable attention was given, however, to examining methods by which the time consumed in the scaling, reduction, and analysis might be minimized. This has resulted in a reduction of one-third in the time involved in scaling; moreover, the methods used provide the results in such form that subsequent reductions and analyses can be largely effected by using International Business Machines equipment. Thus it was possible, by the end of the report-year (June 30,

1946), to scale the accumulation of data during five years of war from the Huancayo Magnetic Observatory, and most of the data are now entered on punch cards. The subsequent reductions and analyses can be effected almost entirely by machine, thereby saving a great amount of arithmetical labor. It is planned by using International Business Machines equipment in the coming year to reduce and analyze similarly the accumulated data from Cheltenham and Godhavn. Together with the material reduced before the war, there would thus be available for analysis and publication bi-hourly means of cosmic-ray intensity (bursts deduced and corrected to constant barometric pressure) for the following stations: Huancayo, June 1936 to June 1946; Cheltenham, March 1937 to June 1946; Godhavn, October 1938 to June 1946. Data obtained during April 1936 to December 1945 at Christchurch have been scaled (by personnel at Christchurch) and the daily means reduced to constant barometric pressure, although bi-hourly means have not been corrected for barometric pressure. Curtailment of supplies at Christchurch during the war resulted in some unavoidable interruptions in recording. Daily means obtained at Teoloyucan during February 1937 to about July 1945 corrected for barometric pressure (reduced at the University of Chicago) should also be available. Since about July 1945 the meter at Teoloyucan has not been functioning properly, and it is planned to correct it during the summer of 1946.

Investigations. Investigations and analyses of the data have been inevitably delayed pending the processing of accumulated records. It is expected, however, that the analyses will be much expedited by use of the International Business Machines apparatus. It is planned to extend some of the investigations, heretofore made on the basis of limited data, to include a longer series. These will include analyses of the world-wide effects which can now be extended practically through a sunspot-cycle; the results should indicate whether there is a permanent external Earth's field which changes intensity with sunspot-cycles. Diurnal variations (solar, lunar, and sidereal) can be rapidly re-examined with the International Business Machines on the basis of much more extensive data. Similarly for the seasonal changes. It is also planned to determine whether the frequency-distribution of burst-size at Huancayo (where burst-frequency is greatest) is influenced by magnetic disturbance and whether it is subject to sidereal or lunar variations. Lunar variations are of interest as a possible means of determining whether the Moon has a magnetic field. With continued use of the computing facilities and sufficient assistance, it may be possible early in 1947 to realize the objectives which the Committee on Coordination of Cosmic-Ray Investigation had in mind when the world-wide program of continuous registration was initiated.

Cosmic-Ray Studies with the Wilson Cloud-Chamber at Bartol Research Foundation of the Franklin Institute

Thomas H. Johnson

In continuation of the studies made possible by financial grants from the Carnegie Institution before the war, R. P. Shutt has analyzed 40,000 cloud-chamber photographs taken with the large 24-inch cloud-chamber at the Bartol Foundation prior to 1942. From these photographs it has been possible to determine the cross-sections for anomalous, non-Coulomb, single scattering of mesons by comparing the scattering in two different thicknesses of lead, a method which had been used in an earlier work published in 1942. The

scattering of mesons of energies above about 500,000,000 volts through angles ranging from 5° to 90° was found to be predominantly anomalous and not of the type that could be described as due to the *electric* fields of the atomic nuclei. This scattering may be attributed to the strictly nuclear forces, and as such would depend upon the spin of the meson.

About 75 photographs showed the simultaneous occurrence of several mesons, and it was shown that many of these were associated in true meson showers. In comparing results obtained with two different thicknesses of lead above the chamber, it was inferred that the probability of production of meson showers is proportional to the thickness, up to 88 cm of lead and 60 cm of concrete. Many unusual photographs were obtained in this series displaying phenomena difficult to interpret in the light of accepted theoretical concepts.

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COSMIC-RAY INVESTIGATIONS AT NEW YORK UNIVERSITY

S. A. KORFF

During the period July 1, 1945 to June 30, 1946, our cosmic-ray work continued. The following investigations have been carried on, financed in part by funds supplied through the Carnegie Institution of Washington.

Study of Geiger counters. Our program for the study of Geiger counters has continued. During the year, we have continued our study of deadtimes and resolving-times and we also have done some further development work on counters with special designs. Triode counters, employing grids to alter the field distribution, were built, and the deadtimes of such counters have been measured. As was anticipated, the deadtimes of counters of this design are substantially less than those of the conventional variety. Further experiments in the direction of reducing operating voltages and shortening recovery times, for example by eccentric positioning of the central wire, are in progress. Other possible filling gases are also being studied.

Study of neutrons produced by cosmic radiation. It will be recalled that our program of study of cosmic-ray neutrons has led us to the conclusion that the energy-distribution of neutrons in the free atmosphere should be determined by scattering in nitrogen. On this basis, an energy-distribution containing a good many neutrons of low velocity but few of thermal velocity was predicted. A balloon flight was carried out in order to study this point. In this flight, a neutron counter was sent aloft, and was equipped with two shields which during the flight alternately covered the counter and left it exposed. Thus a counting-rate curve was obtained with a single counter with two different shields as a function of elevation. From these data, the energy-distribution and the number of neutrons in the atmosphere could be derived. The energy-distribution thus obtained was found to be in satisfactory agreement with the theoretical predictions. The number of neutrons, as well as their energy-distribution, throws some further light on the problem of the processes by which these neutrons are produced. It is believed that they are due to an interesting variety of photodisintegration of the nucleus in which one or more nuclear particles are ejected by the high-energy photons present in the cosmic radiation. It is at present believed that, when a high-energy photon is absorbed by a nucleus,

the effective "temperature" of the nucleus becomes very high, and one or more nuclear particles may be "evaporated" out. Both protons and neutrons are produced thus, and we are now engaged in a detailed study of the process, of its dependence on altitude, and of its connection with other cosmic-ray phenomena.

Personnel. Dr. B. Hamermesh has assisted in most of the experiments described above, and A. Krumbein has a cosmic-ray telescope now under construction.

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DIVISION OF PLANT BIOLOGY

Central Laboratory located at Stanford University, California

H. A. SPOEHR, *Chairman*

During the war years the available staff of the Division centered its efforts on problems arising from the war. As a consequence, the regular investigations had to be deferred. During the past year it has fortunately been possible to bring near to completion most of the work which was undertaken as a contribution to the war effort, and to resume some of the investigations which were interrupted by the war.

In spite of the fact that some of the staff called to participate in scientific war work will not return, and that the regular ancillary help has been lost, the resumption of the previous investigations has proceeded in a gratifying manner. Perhaps the most important part of the renewal of these activities has been a thorough re-examination of objectives and of research programs. It is apparent that the relative importance of scientific problems has been profoundly affected by the intricate social consequences of the war. Also new methods and techniques have become available as a result of the intensive technical and industrial wartime research. This compels a reappraisal of the problems and a consideration of improved methods of solving them.

One of the projects arising out of the war was concerned with the isolation from plant sources of material having antibacterial properties. This largely had its inception in the isolation of such material from the green alga *Chlorella,* and it was found that the antibacterial properties were in part at least ascribable to unsaturated fatty acids which readily underwent photooxidation. Among the products of this photooxidation have been isolated fatty acids with an average chain length of eleven carbon atoms. Special study has been given the acids of this category, primarily capric (C_{10}) and lauric (C_{12}) acids, which are of considerable promise because of their solubility and diffusibility relations and their intrinsic antibacterial properties. *In vitro* tests with these acids have shown them to have definite antibacterial activity against a variety of bacteria. Tests with animals inoculated with *Mycobacterium tuberculosis* and with *Salmonella enteritidis* did not, however, yield encouraging results. The project has been brought to the point where much of the chemical groundwork has been laid and further results are largely dependent upon bacteriological study.

The investigations on the chemical mechanism of the formation of chlorophyll in leaves have been resumed. Inasmuch as magnesium is, as it were, in the center of the chlorophyll molecule, it is important to determine how this element becomes incorporated into this complex organic molecule. It is now established that light plays an important role in mobilizing magnesium from inorganic sources into an organic combination which, in turn, is converted into or utilized for the synthesis of chlorophyll.

One of the most puzzling aspects of the phenomenon of photosynthesis is the manner in which the energy of light is utilized to perform chemical work. There appears to be little doubt but that the pigments of the leaf play an important role in this process. Chemically these pigments are of extraordinary complexity, and an under-

standing of their function is in large measure dependent upon an understanding of their structure. Moreover, the plant kingdom presents considerable variability in the pigments contained in the photosynthetic apparatus. With the development of the method of chromatographic analysis it has been possible to detect pigments heretofore unknown and to establish relationships between groups of plants on a new basis. Hereby genetic and evolutionary avenues are opened to the study of photosynthesis, an approach which has long been overdue.

Investigations of the influence of environmental factors on the chemical composition of the alga *Chlorella* have also been resumed. It has been possible to attain astonishingly large variations in the chemical composition of this organism by altering the conditions of culture. The great flexibility of chlorella cells in reaction to different environmental conditions is indicated by the fact that the percentage of lipoidal material produced may range from 4.5 to almost 86. It is, moreover, possible through the proper control of culture conditions to produce at will cells of any desired composition within these limits.

The investigators in experimental taxonomy have analyzed the data and are preparing a report on a four-year study of the climatic races of the common yarrow, *Achillea*. This species complex furnishes unique material for such a study, for no other comparable group in North America is known to occupy so wide a range of environments. As a corollary to the exceptionally wide climatic range of this group, its members have developed a large number of climatic races. An understanding of the evolution of such races is basic to studies in plant relationships.

The races were tested for their ability to survive and develop in three different environments, viz., at the Stanford, Mather, and Timberline transplant stations. At the same time the individual variability within each of the races was examined. Selected individuals representing key races were also studied in greenhouses at controlled temperatures, and these data were correlated with observations made in the wild and in the experimental gardens. The combined data provide the clearest picture yet obtained of the climatic race, a fundamental evolutionary unit.

The interrelations between the individual, the local population, and the species complex can be traced in *Achillea* and related to physiological characteristics that are determinative in natural selection. Chief consideration in this study is given to such aspects as the range of tolerance of the individual to changes in environment, the genetic diversity within natural populations, and the differences between members of a species complex.

The testing of the hybrids obtained from crossing distantly related species of *Poa*, the bluegrasses, is under way. This work, undertaken as a wartime program in cooperation with the United States Soil Conservation Service in an effort to improve the quality of forage grasses available for western range lands, has demonstrated that hybrids can be obtained from species of *Poa* that produce the great bulk of their seed through asexual means. It was expected that first-generation hybrids from such crosses would likewise reproduce in this manner and breed true. Actual results to date, however, have shown that only about one-third of the hybrids produce their seed in this fashion, and that the other two-thirds revert to the usual sexual method. The genetics of hybrids of apomictic plants is still mostly an unknown field, so that basic investigations are needed to chart methods that may be applied in utilizing such plants in a practical breeding program. Many promising possi-

bilities remain to be tested, but two years are required to bring the offspring of many combinations to maturity.

Field operations for purposes of collection and exploration, which during the war had to be discontinued, have again been resumed especially in connection with the paleobotanical investigations of Dr. R. W. Chaney.

BIOCHEMICAL INVESTIGATIONS

H. A. Spoehr, J. H. C. Smith, H. H. Strain, H. W. Milner, and G. J. Hardin

Antibacterial Properties of Fatty Acids

In the report of last year a brief account was given of antibiotic material obtained from the unicellular alga *Chlorella pyrenoidosa*. It was found that the fatty acids extracted from this plant, though exhibiting no antibiotic activity as first obtained on extraction, developed such activity on exposure to light and air. The development of antibacterial properties is thus apparently due to photooxidation of some component of the fatty acids obtained from the algal cells. It was also shown that the fatty acids obtained from chlorella cells are a mixture containing some highly unsaturated compounds. The formation of antibacterial substances was associated with the photooxidation of these unsaturated fatty acids.

Investigation of the photooxidation of the fatty acids derived from chlorella cells has now shown that these acids undergo splitting into acids of shorter chain length and that a variety of products having antibacterial activity is produced. Some of these products can be separated by distillation. Among the products of distillation are organic acids with an average chain length of about 11 carbon atoms. These acids exhibit relatively high antibacterial activity. Other products showing antibacterial activity, such as aldehydes, are also formed in the complex photooxidation process. These latter compounds are presumably more toxic to animals than are the acids. The preparation of acids of known chemical structure from photooxidation products, in sufficient quantity for experimentation, proved impracticable. Therefore, the investigation was centered on the determination of the antibacterial properties of fatty acids of various chain lengths, authentic preparations of which were available from several sources.

The testing for antibacterial activity by standard methods, such as the Oxford cup test, of a homologous series of chemical compounds, as in the case of the lower fatty acids, presents a number of complications, and strictly comparable values are very difficult to obtain. This is primarily due to the fact that the physical properties, such as solubility, diffusibility, dissociation, and hydrolysis of salts, differ from one member of the series to another. That is, these properties differ with the molecular weight or the number of carbon atoms of each acid. Moreover, the fatty acids and their salts may exist in a number of ionic and associated states. When agar media are employed for the tests, so that the acids or their salts must diffuse through the medium, the relations between solubility, diffusibility, and dissociation become extremely complex, and this complexity is further increased in the presence of animal serum. For these reasons comparative tests with different members of the fatty acid series must be interpreted with great care. It is important in this connection that the organism used for tests of antibacterial activity, *Staphylococcus aureus*, was found to grow well on agar plates containing 1

per cent sodium phosphate as buffer at pH 6.6 to 8.10; at pH below 5.35 and above 9.08 there is no growth. It is, therefore, only within the pH range of good growth that reliable comparative tests of antibacterial activity can be made.

As a consequence of these considerations it was found necessary to make the tests with solutions of the various fatty acids which had been neutralized to definite hydrogen ion concentrations. In these tests the agar nutrient plates were adjusted to the same, or nearly the same, pH as the fatty acid solutions. Probably the most significant result of these tests is the demonstration that near neutrality the antibacterial activity increases with the number of carbon atoms in the fatty acids. This trend is limited by the slight solubility of the acids containing more than 12 carbons, i.e., more than lauric acid. In other words, fatty acids containing more than 12 carbon atoms are too sparingly soluble to exert an appreciable antibacterial effect. On this basis the acids showing the highest antibacterial activity are capric (C_{10}) and lauric (C_{12}) acids, and these acids have a combination of properties in relation to solubility and intrinsic antibacterial activity which makes them superior to the fatty acids both above and below in the homologous series. It is not without interest that results obtained by means of the Oxford cup method were in general duplicated by tests made with buffered liquid broth cultures of *Staphylococcus*. Similar results were also obtained with broth cultures of *Mycobacterium phlei*.

The antibacterial activity of lauric acid was tested against a variety of organisms by means of the streak test. As can be seen in the accompanying table, bacteria show considerable variation in their resistance to lauric acid. For these tests agar nutrient containing 1 per cent sodium phosphate and various concentrations of sodium laurate at pH 7.5 was streaked with the bacteria and incubated for two days at 37° C.

EFFECT OF SODIUM LAURATE ON VARIOUS BACTERIA AS DETERMINED BY STREAK TEST

Conc. of lauric acid (%) / Organisms	2.5	1.25	0.625	0.312	0.156	0.078	0.039	0.02	0
Pseudomonas aeruginosa	0	0	+	+	+	+	+	+	+
Pseudomonas fluorescens	0	+	+	+	+	+	+	+	+
Corynebacterium xerosis	0	0	0	0	0	±	+	+	+
Mycobacterium phlei	0	0	0	0	0	±	±	+	+
Staphylococcus aureus	0	0	0	0	0	+	+	+	+
Sarcina lutea	0	0	0	0	0	±	+	+	+
Escherichia coli	0	0	+	+	+	+	+	+	+
Aerobacter aerogenes	0	0	+	+	+	+	+	+	+
Bacillus megatherium	0	0	0	0	0	0	+	+	+
Bacillus subtilis	0	0	0	0	0	+	+	+	+

The antibacterial activity of fatty acids containing 10 and 12 carbon atoms which has been here briefly described is disclosed by tests made in relatively simple systems. The fact should also be mentioned that in more complex lipoidal systems the antibacterial activity of lauric acid, for example, is less than when tested under simpler conditions. As an illustration, lauric acid dissolved in olive oil does not readily penetrate into an agar test plate

even though this is buffered with 1 per cent sodium phosphate at pH 7.5. Similarly, in broth containing a high proportion of rabbit serum sodium laurate is much less effective against *Staphylococcus* than in broth alone. Analogous inhibiting effects of rabbit serum on the activity of sodium laurate against *Staphylococcus* have also been observed by the cup test method.

A prime requisite in an experimental investigation of this nature, especially where animal experiments are involved, is an adequate supply of the substance under investigation. Of the many natural fats obtainable from plants, relatively few are rich in capric and lauric acids. Lauric acid (*n*-dodecanoic acid) derives its name from the botanical family of Lauraceae, many members of which elaborate seed fats consisting largely of this acid. A notable example is the California laurel, *Umbellularia californica*. The dry seeds of this plant contain over 60 per cent of fat, and this fat contains 62 per cent lauric acid and 37 per cent capric acid. The seeds were available in quantity locally, and some 18 pounds of the fat was extracted for experimental purposes. The fat is pale yellow in color, and is solid at room temperature but melts below 35° C. The laurel nuts have a burning, astringent taste, but the extracted fat has a sweet, cooling taste very much like that of fresh butter. The free fatty acids are readily obtained from the fat through saponification. The mixture of fatty acids thus obtained melts at 29–30°, as compared with 31° for capric acid and 43.5° for lauric acid. This mixture of acids has a very disagreeable burning taste.

The fat itself exhibits no antibacterial activity. But by action of the fat-splitting enzyme steapsin, the fat is converted into a mixture of free fatty acids which is antibacterial. The neutralized mixture of fatty acids gave test rings by the Oxford cup method comparable in diameter to those formed by capric and lauric acids. The concentrations of the salts of this acid mixture that inhibited the growth of various bacteria, as determined by the streak tests, were similar to those of lauric acid.

In view of the experience with many other antibiotics, it need hardly be emphasized that there is a great gap between the demonstration of antibacterial activity of a substance by means of *in vitro* tests and the successful application of this substance in combating infection in animals. The case of lauric and capric acids as antibiotics is no exception. On the basis of cup tests it was concluded that a concentration of 0.1 per cent lauric and capric acids might be able to inhibit the growth of bacteria invading the blood or body fluids of an animal. For a 75-kg. man, therefore, 75 g. of these acids would be required, which seemed a reasonable amount of acid or fat for the body to handle. It was found, however, after injection intraperitoneally into guinea pigs of the sodium salts of acids of laurel fat, or after the injection of the fat and also after feeding pellets impregnated with 10 per cent of the fat, that there was no antibacterial activity in the serum of these animals as measured by the cup test or in broth tests.

Through the cooperation of Dr. Sidney Raffel, of Stanford University, two carefully controlled experiments were carried out to determine whether laurel-seed fat, and the acids derived therefrom, exerted an effect on the course of disease in infected animals. The first of these experiments was with guinea pigs infected with *Mycobacterium tuberculosis*. The laurel-seed fat was given by impregnating the standard pellet food with 15 per cent of the fat, and the animals were infected on the 15th day of feeding. Feeding of the fat was continued for 13 weeks after infection. The results of the autopsies of the control and fat-fed animals, on the Feldman index,

revealed no definite beneficial effect of the laurel fat on the course of the disease.

The other animal experiment was carried out with mice infected with *Salmonella enteritidis*. In this case the laurel-seed fat was given either as such, as the free fatty acid, or as the sodium salt of the fatty acid, in all cases mixed with the food. The animals were infected on the 21st day of feeding and the experiment was continued 6 weeks after the beginning of feeding. In this case also there was no significant difference in mortality or in time of death between the control group of animals and those which had been fed preparations of laurel-seed fat.

The fate of a fat, a fatty acid, or its sodium salt, when taken into the digestive tract or injected into an animal, is in itself an extremely complicated problem, the further investigation of which entails highly specialized facilities and experience. The purpose of this investigation was to determine the chemical nature of some substances having antibacterial activity which can be derived from plant sources and which are readily obtainable. The more extensive testing of these substances clearly lies in the field of bacteriology and medicine. On the basis of experience thus far obtained with capric and lauric acids, it seems highly probable that a relatively mild antibiotic such as these, in the form of soaps rich in these acids, may have useful antiseptic properties.

Organic Magnesium and Chlorophyll Formation in Leaves

In the seedlings of a great many plants, when grown in complete darkness, only minute quantities of chlorophyll are detectable. On exposure to light the leaves of these plants gradually increase in chlorophyll content through a process which is still very incompletely understood. The synthesis of so complex a molecule as chlorophyll is an exceedingly intricate process, and one of the most remarkable aspects of this synthesis is the incorporation into the organic molecule of an atom of magnesium. This magnesium is derived from purely inorganic sources within the chloroplast-containing cells. Dr. Smith has resumed investigations designed to gain information on the conversion of inorganic magnesium into organic magnesium in relation to the process of chlorophyll formation in leaves.

By examining etiolated leaves, initially chlorophyll-free, and leaves which in the course of illumination have developed an increasing quantity of chlorophyll, different stages in the process of greening can be followed. For such an investigation certain of the distinctive properties of chlorophyll, such as its characteristic absorption spectrum, its definite magnesium content, and its ready solubility in ether, are of great value. A comparison of the magnesium content and of the spectral absorption properties of the ether extracts of the leaves at the various stages of greening gives indication of the amount of magnesium which is in organic form and of the amount which has been incorporated into chlorophyll. For this purpose etiolated barley seedlings were illuminated for various periods of time. For each period the total ash and total magnesium content of the leaves as well as their chlorophyll and ether-soluble magnesium content were determined.

The etiolated seedlings before illumination contain only a trace of chlorophyll. In these seedlings the amount of ether-soluble magnesium, although small, is many times the amount contained in the chlorophyll present. In the early stages of illumination the amount of ether-soluble magnesium increases and continues to be greater than would be required for the

increase in chlorophyll. After the initial stages of greening, the amount of ether-soluble magnesium in excess of the chlorophyll magnesium increases relatively little, and in the later stages of greening the ether-soluble magnesium is only slightly in excess of the quantity of magnesium represented by the chlorophyll content. Besides chlorophyll, other ether-soluble substances increase on illumination of the leaves. The initial increase in these substances is relatively much greater than the increase in chlorophyll, and even in the later periods of illumination the production of these substances exceeds the chlorophyll production very considerably. As the periods of illumination are lengthened, there is also an increase in the content of total ash and of total magnesium in the leaves.

The quantitative relations of chlorophyll and of the different forms of magnesium during the process of greening indicate that etiolated barley seedlings initially do not contain a reservoir of ether-soluble magnesium large enough to account for all the chlorophyll formed during illumination. They demonstrate that light causes the magnesium to be mobilized from inorganic sources and to be incorporated into organic compounds, and ultimately into chlorophyll. Whether the organic magnesium compounds present in the etiolated seedlings before illumination are converted into chlorophyll is not yet established. But the results indicate that the organic compounds of magnesium formed during illumination are so converted.

These observations lead to another consideration of the possible significance of magnesium mobilization in connection with the photosynthetic process. It has now been demonstrated that, under the influence of light, magnesium is mobilized from inorganic sources, to be incorporated into organic compounds and into the chlorophyll of the photosynthetic apparatus. Earlier observations by Dr. Smith have demonstrated that inorganic magnesium compounds participate in the absorption of carbon dioxide from the environment by the leaves. This act probably represents the first, or an early, step in the photosynthetic process. Considered as successive steps, these two processes suggest a possible path by which the absorption of carbon dioxide and its entry into the photosynthetic system is accomplished.

The relatively rapid formation of fat-like substances during the initial stages of greening is of considerable interest. It has been known for some time that the formation of photosynthetic pigments and the development of photosynthetic capacity in young leaves do not run parallel. The rate of photosynthesis in such leaves per mol of chlorophyll is higher than in mature leaves. It now would appear that under these conditions the products of photosynthesis also may differ. It is commonly assumed that in mature leaves carbohydrates accumulate predominantly, whereas these results would indicate that in very young leaves there is an accumulation of fats.

The relations of organic magnesium and of chlorophyll formation were also investigated in normal and albino corn seedlings. The albino seedlings lack the capacity to form chlorophyll in the light. For comparison, albino and green corn seedlings were grown under natural illumination and the chlorophyll and ether-soluble magnesium of the two were determined. The albino seedlings were found to contain a small amount of ether-soluble magnesium, though this was in excess of the minute amount of chlorophyll present. The ether-soluble magnesium in green seedlings, however, was about equivalent to their chlorophyll content, which was considerable. It would appear, therefore, that albino seedlings not only lack the capacity

to form chlorophyll, but also do not form any considerable amount of ether-soluble magnesium.

Plant Pigments

Investigations on the pigment complex of the photosynthetic apparatus of plants were interrupted during the war years, in part because of occupation with other problems, and in part because of difficulty in obtaining fresh material from the seacoast. During the past year Dr. Strain has been able to resume these investigations.

Algal pigments. On the basis of extensive investigations of the pigment complex in higher plants it has been concluded that the chlorophylls are always accompanied by beta-carotene, an unsaturated hydrocarbon, with sometimes smaller quantities of the isomeric alpha-carotene. In the past year, examination of the pigments of algae has shown that beta-carotene is not always the principal carotene of autotrophic plants. In the green alga *Codium fragile,* alpha-carotene is the principal substance of this group, only traces of beta-carotene being present. Although it is still not known what function the carotenes play in the metabolism of plants, it would seem that alpha-carotene can replace beta-carotene in the vital reactions that take place in the green parts of these plants.

It is possible that the pigments of the photosynthetic apparatus give intimation of some courses through which plants have passed in their evolutionary development. The universal occurrence of chlorophyll *a* together with carotenoids (xanthophylls and carotenes) in all autotrophic plants above the bacteria may be taken to suggest a common origin for the photosynthetic apparatus of these organisms. Perhaps only one type of photosynthetic apparatus was developed; or in some cataclysm, such as the production of oxygen in an anaerobic world, organisms with only one kind of photosynthetic mechanism may have survived. It is striking that, but for one exception discovered this year, the pigments that accompany chlorophyll *a* are characteristic of plants belonging to the same or to related taxonomic groups. For example, accompanying chlorophyll *a,* chlorophyll *c* is common to diatoms, dinoflagellates, and brown algae, three important groups of marine plants. Fucoxanthin is the principal xanthophyll of diatoms and brown algae. Accompanying chlorophyll *a,* chlorophyll *b* and the xanthophyll lutein occur in the green algae and in all higher plants. This rather uniform distribution of pigments in plants belonging to related taxonomic groups and the slight variation of pigments in plants within a group may indicate that the several characteristic pigments originated early in the evolutionary development.

The exceptional occurrence of unique pigments, mentioned above, has been found in the green alga *Codium fragile.* This organism contains relatively large quantities of two hitherto undescribed xanthophylls. In relative adsorbability and in spectral absorption properties, these two xanthophylls resemble the fucoxanthin of diatoms and brown algae. These xanthophylls were not found in other green algae such as *Chaetomorpha aerea, Ulva lobata,* or *Chlorella pyrenoidosa.* Traces of the two new xanthophylls may have been present in the green alga *Spongomorpha coalita.* The presence of these xanthophylls along with alpha-carotene as the principal carotene of *Codium* suggests that the evolutionary pattern of this organism has differed markedly from that of other green algae. *Codium* contains chlorophyll *b* as well as chlorophyll *a,* and in this respect its pigments are characteristic of the green algae.

Thus far the pigments of relatively few plants have been subjected to careful examination. For the most part, these organisms have been adapted to narrow ranges of temperature, light intensity, and salt concentration. Examination of the pigments of a greater variety of plants and of those from different habitats may give further clues to these relationships and to the essential pigment complex of the photosynthetic apparatus.

Spectral properties of chlorophyll a. The spectral properties of chlorophyll *a* in living plants differ from those of the chlorophyll dissolved in organic solvents. This difference is evidenced by the occurrence of the spectral absorption maximum in the plant at about 678 mμ, whereas for solutions of chlorophyll *a* in organic solvents the absorption maximum is at 660 to 670 mμ. In order to gain further evidence on this question, the spectral absorption properties of chlorophyll have been determined in a number of living algae. Included in this study were two species of diatoms, five species of green algae, about a dozen species of brown algae, and an equal number of species of red algae. In all these plants the spectral absorption maximum of the chlorophyll was found to be at 678 mμ, indicating that the chlorophyll occurred in the same physical or chemical state. This observation leads to the supposition that so far as the chlorophyll is concerned the photosynthetic apparatus is the same in all plants, and emphasizes the highly specific nature of this system.

Some attempts have been made to prepare chlorophyll *a* in such a state that its spectral absorption maximum should occur at 678 mμ. To this end the chlorophyll was dissolved in aqueous solutions of the neutral sodium or potassium salts of the lower fatty acids. Solutions containing 10 per cent of the salts of pelargonic acid and of capric acid dissolved relatively large quantities of chlorophyll *a*, forming deep-green solutions with absorption maxima at about 670 to 672 mμ. This corresponds to the spectral absorption maximum of chlorophyll in killed plant cells rather than to the maximum of chlorophyll in the living tissue.

Pigments and reproduction. Special interest attaches to the chloroplast pigments in the reproductive stages of some of the algae. There has been evidence from several sources that these pigments and related substances may play a role in these stages of the development of the plant. An investigation has been undertaken to determine the nature of the pigments and their quantitative relations in sexually differentiated tissue of a marine alga.

Through the cooperation of Professor Gilbert M. Smith, of Stanford University, considerable quantities of the gamete-bearing parts of *Ulva lobata* were obtained for analysis of their pigment content by means of chromatographic adsorption. Some of these plants produce only male flagellated cells; others produce only female flagellated cells. These gametes, which are positively phototactic, are formed in the peripheral parts of the thallus, where every single vegetative cell divides simultaneously to form about 32 female cells or about 128 male cells. The parts of the thallus bearing male cells are almost tan in color; the parts bearing the female cells are greener but not such a clear green as the vegetative parts of the thallus. By means of these differences in color the sexually differentiated parts of the thallus can be clearly distinguished by the experienced observer.

It was found that the vegetative parts of the fresh thallus, either from male-producing plants or from female-producing

plants, contained the same pigments in the same proportions. The principal pigments of the vegetative thalli were chlorophyll *a*, chlorophyll *b*, lutein, and beta-carotene. Other xanthophylls and traces of alpha-carotene and a more adsorbed carotene were also present. The total amount of chlorophyll in the fresh thallus was about 0.26 per cent, and the ratio of chlorophyll *a* to chlorophyll *b* was about 1.6.

The male gametes contained about 0.82 times as much chlorophyll as the vegetative thalli and more than 5 times as much carotene. This carotene was composed principally of beta-carotene with a relatively large proportion of gamma-carotene and smaller portions of a more adsorbed carotene and of alpha-carotene. This increase in carotene and decrease in chlorophyll as compared with the vegetative thalli results in a large increase in the ratio of carotene to chlorophyll and undoubtedly accounts for the tan color of the male gametes.

The female gametes contained about 1.45 times as much chlorophyll as the vegetative parts of the thalli and more than 5 times as much carotene. The latter was identical in composition with that of the male gametes. In the female gametes the lower ratio of carotene to chlorophyll probably accounts for the greener color as compared with the male gametes. In both male and female cells the ratio of chlorophylls to xanthophylls was approximately constant.

In the vegetative thalli and in both the male and female gametes the ratio of chlorophyll *a* to chlorophyll *b* was constant. Apparently the chlorophylls and the xanthophylls of the vegetative cells are distributed uniformly among the gametes. In spite of the uniform distribution of these pigments there is a definite increase in the content of carotenes, particularly of gamma-carotene.

Both male and female gametes contain "eye spots" which control their phototropic sensitivity. Thus far it has not been possible to determine the distribution of the pigments in the "eye spots" relative to that in the plastids, but it is possible that carotenoids may be involved in this rudimentary vision of the gametes just as other carotenoids are linked in the phototropic responses of other plants and in the visual processes of animals.

Chromatographic adsorption analysis. The extensive application of the chromatographic adsorption method for the resolution of mixtures of plant pigments has revealed some significant peculiarities of this technique. These observations have bearing on many uses to which this technique is put in virtually all branches of chemical analysis.

In the course of the investigations of the pigments of algae it was found that the relative positions occupied by the different pigments as they are washed through the powdered adsorbent depend upon a variety of conditions. These conditions are the solvent used, the adsorbent, temperature, concentration, and the presence of impurities. In other words, the relative positions taken by various pigments in the course of resolution in an adsorption column are not invariably the same. Variation of the conditions mentioned may be utilized to increase the sensitivity and the resolving power of the columnar adsorption method. The fact that there is variation in the sequence of adsorbed substances with changes in conditions demonstrates that the relation between the molecular structure of the pigments and their adsorbability is extremely complex. These observations emphasize the precautions which must be observed in the use of this adsorption technique and also point the way to new and more refined applications.

The Production of Organic Matter by Chlorella pyrenoidosa

The degree to which the chemical composition of a plant can be altered by changes in the environmental conditions under which it grows is a question of both theoretical and practical significance. In a previous report (Year Book No. 42, p. 85) a brief account was given of investigations which had been carried out on variations in the organic constituents of the alga *Chlorella pyrenoidosa* when grown under different conditions. For this purpose the modifications in environmental conditions included a wide variation in the concentration and relative quantities of the mineral nutrients contained in the culture solutions, a wide range of light intensities, temperatures ranging from 15° to 30° C., and several concentrations of carbon dioxide in air and in nitrogen. These experiments revealed certain definite trends of the influence of environmental factors on the composition of the substances synthesized by the chlorella cells.

In view of the very large number of cultures which had to be examined, a simple method of analysis was employed, the principle of which was also described in the earlier report mentioned. In essence, this method gave information regarding the degree of reduction of the total organic constituents of the plant. By this means it was possible to establish, for example, whether the plant cells were composed primarily of compounds of the nature of carbohydrates or of fats, and, in a measure, to determine the relative proportions in which carbohydrates, proteins, and fats were present. The degree of reduction of the organic material constituting the entire body of the plant has been designated the R-value. On this basis, for example, a hydrocarbon such as hexane has an R-value of 88.42; a fat, one of 67.5; protein, 42; and cellulose, 29.70.

Considerable theoretical interest attaches to the production of cells with a high R-value, that is, cells containing a relatively large proportion of fats or hydrocarbons. These investigations were resumed during the present year by Spoehr and Milner, primarily with a view to discovering conditions favorable for the growth of cells having a high R-value.

The earlier experiments had seemed to indicate that the production of material of high R-value was associated with a small yield of cells, and that a minimal quantity of available nitrogen was a necessary factor for such cultures. The highest R-values then obtained, 57 to 58, were from cultures to which no nitrogen compounds had been added and in which the yield of cells was only 0.15 to 0.19 g. dry weight per 2000 ml. of culture solution. Further investigation revealed that cultures to which a small quantity of fixed nitrogen had been added would also reach high R-values if grown for a longer time, and that greater yields were obtained. This observation has led to the discovery that, in a given chlorella culture, increase in cell yield and increase in R-value proceed in the same direction. In any particular culture, as the cell yield increases with time, the R-value also increases. It now appears that the production by the cells of material of high R-value is dependent upon the near exhaustion of the available supply of fixed nitrogen. If the available fixed nitrogen in the culture solution is low, the yield of cells will be low and high R-values will be attained in a relatively short time. With greater fixed nitrogen supply, yields of cells increase and more time is required for the cells to attain a high R-value. In other words, the yield of cells having a high R-value and the length of time required to reach this R-value both increase with increasing nitrogen supply. This relation holds up to the point where increasing NH_4 ion concentration

becomes deleterious, or where more fixed nitrogen is supplied than the cells can utilize. In the latter case, cell yield continues to increase with time, but high R-values are not attained. Thus cultures with a large fixed nitrogen supply as nitrate have never reached high R-values, though very large cell yields were obtained. It is now apparent that a culture can be brought to produce cells in large yield, composed of material of high R-value, through choice of the proper culture solution and of long enough growing time.

In the course of development of a culture of high R-value, cell division occurs rapidly in the early stage when there is an ample supply of fixed nitrogen. During the first stage of development the cell count and the yield in weight of cells increase in a roughly parallel fashion. The R-value changes but little, reaching about 41 to 45, increasing slightly with age. A point is reached when cell division ceases, and a pronounced change can be observed in the culture. The cells remain alive, they increase in both size and weight, and the R-value rises sharply. With advanced age the rate of increase in cell weight and in R-value diminishes. A clue to the changes which take place as the R-value increases in this later stage of development of the culture is afforded by examination of the yields in terms of dry weight as compared with fresh weight. For example, in a series of five cultures in the same medium, harvested after 14, 21, 28, 42, and 63 days, the fresh weight of the cells from cultures of increasing age actually decreased, while the dry weight and the R-value steadily increased. This suggests that with increasing age there is a decrease in some hydrophilic constituents of the cells, accompanied by the accumulation of anhydrous constituents, or those which do not hold water, such as lipoids or possibly hydrocarbons.

Another striking observation is that the cells with a high R-value are more efficient accumulators of radiant energy than are the cells of lower R-value, when the cultures of each are grown under optimal conditions. For these calculations the total energy stored may be expressed as the product of grams yield and R-value, the latter being proportional to the heat of combustion. Although these calculations are subject to more exact and direct efficiency measurements, it would appear that the high R-value culture not only stored more total energy, but did so in a shorter time and at lower energy input than was available to the lower R-value cultures.

The astonishing range in R-values, from 38 to 63, obtained from cells grown under a wide variation of external conditions must be due to a very considerable difference in the chemical constituents of the cells. For the moment we are more concerned with the fact that such a wide difference in composition of the cells is attainable and with the nature of the chemical substances involved than with the question as to how the external conditions bring about this variation in composition. The more exact determination of the chemical nature of the cell constituents is dependent upon chemical analysis. But it is now possible to produce at will cells of any desired R-value within the limits 38 to 63. A preliminary indication of what proportions of certain constituents of known composition may be expected is afforded by calculations based upon the elementary analysis and R-values of the cells. For this purpose we may take the percentage of nitrogen times 6.25 to represent the percentage of protein. The R-value of protein, calculated from published carbon, hydrogen, and nitrogen analyses, is about 42. It may be further assumed that the carbohydrate fraction of chlorella has an R-value intermediate between those of hexose and

of starch or cellulose, or 28. Assign to the remainder of the plant material an average R-value equal to that of fat, 67.5. From the R-values of the various samples of chlorella and their percentages of nitrogen, an estimate can be made of the fraction of protein, carbohydrate, and lipoid. Examples of the possible composition of some of the chlorella cells calculated on this basis are as follows:

R-value	Protein (%)	Carbohydrate (%)	Lipoid (%)
38	58.0	37.5	4.5
42	50.0	32.3	17.7
50	28.3	26.2	45.5
56	15.7	19.0	65.3
63	8.7	5.7	85.6

It is a rather remarkable phenomenon that the same species of organism should show a variation in composition ranging from 4.5 to 85.6 per cent lipoid, depending upon the conditions under which it is grown. It should be emphasized that these results are subject to confirmation by chemical analysis for particular compounds or classes of compounds. Yet it is safe to say that chlorella cells exhibit great flexibility in their reaction, as expressed in their chemical composition, to different environmental conditions. Perhaps the most striking feature of this property is the large percentage of highly reduced carbon compounds, probably in the form of fat, which these organisms are capable of synthesizing.

It is realized, of course, that these experiments give no information as to how these differences in composition are produced. It is a question for special investigation to determine whether certain strains are selected through particular environmental conditions, or whether there is involved a modification as a result of which all cells of the population attain the differences in composition observed. The selection of strains of high-R-producing cells appears improbable on the basis of evidence obtained thus far.

EXPERIMENTAL TAXONOMY

JENS CLAUSEN, DAVID D. KECK, AND WILLIAM M. HIESEY

The relations of plants to each other and to their environment and the evolutionary laws that govern their natural arrangement in variously ordered groups are basic subjects of study in the program of experimental taxonomy. In this program wild forms are used because in these the evolutionary steps are more fully revealed. Morphology, plant distribution, ecology, genetics, and cytology, coordinated, are the tools used in the investigations of the evolution of wild plant forms.

Two investigations on the organization of plant life have been pressed during the present year. One of these is the study of climatic races in *Achillea*. The climatic race is a basic natural unit in the evolutionary sequence. The *Achillea* investigations bring together information on the most complete series of climatic races yet found. This series covers every major zone in the extremely varied climatic transect across central California. The *Achillea* study therefore aids in the understanding of other plant groups, and the general principles, because of their application to groups less well suited to experimentation, are of basic importance. A detailed analysis has been made of the transplant and physiological data obtained from the *Achillea* experiments, and a complete report is being prepared.

The other investigation, made in cooperation with the United States Soil Conservation Service, undertook to test the possibilities of improving the western

range-grass Poas through breeding. This study covers a higher order of evolutionary units than those of *Achillea*. The units in *Poa* belong to taxonomically distinct sections within the genus. The agriculturally important species of *Poa* produce almost all their seed without fertilization, and it was desirable to attempt the production of nonsegregating hybrids through the crossing of such forms. Little was known concerning the breeding possibilities in plants of this type. From the rather limited results obtained in previous experiments with similar material it was expected that when the hybrids were successfully produced the greatest hurdle would have been overcome, and that by selecting the most promising of these, new and constant lines could be procured. By growing approximately 6000 plants of the crucial second hybrid generation at Stanford in the summer of 1946, however, it was found that two-thirds of the F_1 hybrids had become sexual and segregated in the second generation, while only one-third remained constant. This situation complicates the breeding program, but extends the usefulness of *Poa* to basic scientific researches.

Climatic Races in Achillea

During the course of geologic ages the species of higher plants that inhabit the diverse climates of the earth's surface have undergone profound evolutionary changes. The plants now living are the veteran survivors of countless battles for existence with their physical environment and with living competitors, both plant and animal. In the arena of this indeterminate, endless struggle evolution takes place: new species, subspecies, and races come into being, while others that once flourished have perished or are relegated to minor niches in the economy of plants.

In the face of these rugged evolutionary forces, it is not surprising that many plant forms became casualties in the struggle for existence. In some groups the proportion of surviving forms is greater than in others, but even those that have the most complete set of survivors must have lost many forms. The *Achillea millefolium* complex is extraordinary in that its components cover most of the northern hemisphere, and have successfully invaded almost every climatic niche. In this process, striking evolutionary adjustments have taken place resulting in very diversified races.

The experiments on the climatic races of *Achillea* have now been completed and the results analyzed and prepared for publication. In these experiments populations were studied from frequent intervals along a transect across central California from the coast to the eastern base of the Sierra Nevada. These populations include forms from the mild, equable climates of the coast, others that grow farther inland in arid regions with only a short period of winter rainfall, giant forms that inhabit moist areas in the hot San Joaquin Valley, Sierran races that grade by continual steps from the tall forms at the lower elevations to tiny alpines above timber line, and again taller forms from the eastern escarpment of the Sierras and the plateau region of the Great Basin. In addition, latitudinal races ranging from central California to Alaska and differing widely both in appearance and in genetic composition have been studied.

Seedling populations of 60 individuals from a series of 22 representative altitudinal and latitudinal environments were used, as described in Year Book No. 41, pages 127–132. From most of these populations 30 representative individuals were divided and the resulting ramets grown simultaneously in the Stanford, Mather, and Timberline gardens, situated near sea

level and at 4600 and 10,000 feet altitude, respectively. In this fashion the resulting genetically identical populations were subjected to the very different climates of the three stations and the differences observed in appearance, vigor, and survival of any individual were assignable to the environment alone. Moreover, selected individuals were grown in the air-conditioned greenhouses of the California Institute of Technology at Pasadena, and these have provided information on the growth of climatic races under different conditions of temperature and light (see Year Book No. 43, pp. 77–79). The information gathered from all these studies, though still far from complete, provides a considerably more detailed analysis of the nature and physiological basis of climatic races than has hitherto been available.

The maritime and coastal races. In local coastal areas directly exposed to strong sea winds, dwarf maritime forms of *Achillea* occur. These have thick leaves, short stems, and massive flat-topped inflorescences, and occur on exposed coastal bluffs from San Luis Obispo County to Oregon. Taller and less coarse forms grow farther inland on the coastal side of the Outer Coast Range, and even very close to the ocean but on less exposed sites. The dwarf and tall types are genetically distinct, as can be clearly seen when the two are grown side by side in the same garden. Population samples from the two kinds of environment show overlapping variation, although their differences are statistically significant.

All these forms occur in essentially the same climatic zone in so far as temperature, rainfall, and the characteristics of the seasons are concerned. The chief environmental difference appears to be the intensity of sea winds and the presence of salt spray in the outer coastal zone. When vegetative divisions of the dwarf and tall types are grown in the Stanford, Mather, and Timberline gardens, their characteristic differences remain, but their over-all reactions and capacity for survival are essentially alike. At Stanford, as in their native environment, they grow vigorously, and, when irrigated, continue in active growth for the entire year. At Mather, where they are forced into a period of dormancy for six months during the colder winters, both begin spring growth with poor vigor after the snows have melted, during April, but remain green during the summer and gain sufficiently in strength as the season progresses to be able to survive the following winter. At Timberline, almost without exception, they die during the first winter.

In the temperature-controlled greenhouses the dwarf and tall coastal races thrived best when the day temperatures were kept cool (17° C.) and the night temperatures were either cool (13°) or cold (7°). These temperatures are closely comparable with those of their native environment along the coast of central California, where there is relatively little seasonal or diurnal variation. Under natural conditions these coastal plants make their maximum growth during the cool but rainy winter period.

The foothill forms. In contrast with the coastal plants, there is a race complex of *Achillea* which is peculiarly well fitted physiologically to survive on the dry inland slopes and valleys of the Coast Ranges and on the arid lower foothills on both sides of the Great Valley of California. It becomes most active during the cool winter months, when the rainy season is at its height although frosts occur. It thrives at Stanford, which is within the natural distributional range of this race. It flowers and matures its seed earlier than any of the other forms from the California transect, and then quickly becomes dormant

during June, when the temperature rises and the supply of water is exhausted; it resumes activity during the following winter.

Foothill forms grown at Mather become dormant during the colder winter there and emerge in spring in a weakened condition. They develop a few rosette leaves and, following their customary pattern, rapidly develop flowering stems. The stems are much dwarfer, fewer, and more poorly developed than those on divisions of the same plants at Stanford. This winter dormancy does not prevent them from becoming summer-dormant as well when temperatures rise and the black soil around their rhizomes becomes very hot and dry. The growing season of these forms at Mather is thus crowded between two periods of dormancy. With such a short growing season they weaken much faster than the coastal races, and die within a year or two after transplanting. At Timberline the foothill races fare no better than the ones from the coast, for practically no plants survive even a single winter.

Preliminary experiments under controlled conditions suggest that the summer dormancy typical of the foothill races is induced by warm temperature, for divisions of a plant placed in a greenhouse having a cool day of 17° C. and a cool night of 13° C. remained green and active during the summer, whereas other divisions of the same plant became dormant at the constant high temperature of 26° C. Other propagules of the plant kept out of doors during the summer at Pasadena and at Stanford likewise became dormant. Under all these conditions sufficient moisture was supplied, so that lack of water was not a limiting factor.

The San Joaquin Valley race. Flanked to the east and west by the foothill race, a giant form grows in moist bottom lands in the center of San Joaquin Valley in a climate marked by long, hot summers. Unlike the foothill races, it remains active at Stanford during the summer, and some of its individuals have become more than 180 cm. tall.

Unfortunately war conditions prevented the testing of this interesting race at the mountain stations, but experiments under controlled greenhouse conditions showed that it was able to grow vigorously under constant high day and night temperatures of 26° C. These are the conditions under which the foothill forms grew poorly and passed into early dormancy, and under which the coastal forms were distinctly weak. The San Joaquin Valley race, on the other hand, was definitely inhibited when exposed to a cool day of 17° and a cold night of 7°, conditions under which the coastal and maritime plants made their best growth. The evidence points to the conclusion that the San Joaquin Valley race is physiologically specialized to function effectively in the kind of environment to which it is native.

The Sierran races. A complete series of races of *Achillea* begins at the lower altitudes of the Sierra Nevada near the lower fringes of the coniferous forest at 3000 feet, and ranges up to the crest above timber line at 11,000 feet. Samples of these populations were taken at altitudinal intervals of about 1000 feet. In every sample taken a considerable array of individual variation was found, yet most populations were sufficiently distinct from the others to be readily recognized as statistically different.

Plants from near Groveland, at 3000 feet, with a climate having moderately cold winters and some snowfall, attain marked vigor at Stanford, near sea level, where they, like the coastal races, are winter-active. At Mather, at 4600 feet, divisions of the same plants are definitely shorter in stature, but still grow well. At Timberline, at 10,000 feet, only a small fraction of

these plants survive, and these are unable to mature seed; yet they survive significantly better than the coastal and foothill races, which consistently die.

The race native at Mather grows most vigorously in the Mather garden. It also succeeds well at Stanford with a longer growing season, some individuals remaining evergreen while others become dormant for a short period during the winter. At Timberline it survives better than plants of the Groveland race from a habitat 1600 feet lower in elevation, and the survivors attain better development.

Populations from Aspen Valley at 6400 feet, Yosemite Creek at 7200 feet, Tenaya Lake at 8200 feet, Tuolumne Meadows at 8600 feet, Timberline at 10,000 feet, and the upper limits of the species at Big Horn Lake at 11,000 feet survive and flower at Timberline with lesser or greater success, and at Stanford they are winter-dormant and summer-active. When their reactions are studied, most of these populations stand out as distinctly different from one another. At Stanford and Mather the Aspen Valley and Yosemite Creek races are taller than those from higher elevations, but shorter than those from Mather and Groveland. At all stations these two populations flower considerably later than those from higher altitudes, and at Timberline they are unable to ripen their seed before winter weather begins. The Aspen Valley race is the less successful in the alpine climate, and consistently flowers about a week later than the Yosemite Creek race at all three stations.

The four populations from Tenaya Lake to Big Horn Lake show considerable morphological resemblance, having short, narrow leaves and gray herbage (*Achillea lanulosa* ssp. *alpicola*) as contrasted with the plants from Aspen Valley and Yosemite Creek, which have wider and larger leaves and more greenish herbage. The Tenaya Lake race is the least alpine of the four from higher elevations, being significantly taller at Stanford. In contrast, the Big Horn Lake race has the most alpine characteristics, being much reduced in size at Stanford and Mather, and flowering earlier than any of the others at all stations.

Even the plants from Big Horn Lake, which represent the extreme alpine form, grow with some success at Stanford. They pass into dormancy for about three months during the relatively warm winters there, and emerge in March in a weakened condition. As the season progresses they gradually improve their vigor, and new leaves continue to develop during summer and late fall, although flowering is erratic and meager. At Timberline, on the other hand, this alpine lies dormant nine months of the year, yet emerges in vigorous spring growth as soon as the winter snows have melted in early July. The flowering stems develop quickly, becoming fully mature before the end of the growing season. It is far more vigorous at the alpine station than at Stanford, and, like the other races of *alpicola,* suffers markedly at Mather during the warm and dry summers. There these shallow-rooted alpines apparently become so dry that their growth is checked, and the development of flowering stems is almost entirely prevented.

The alpines appear to have a rather high temperature threshold for the inception of spring growth, for they remained inactive under controlled conditions when days were kept cool at 17° C. and nights cold at 7°. Under the same conditions the coastal forms flourished and flowered freely.

Races from the Great Basin area. A population from Conway Summit, Mono County, at 8100 feet, on the eastern escarpment of the Sierra Nevada, and one from near Leevining, at 6600 feet, differ from

each other and from the forms from the western slope of the Sierra Nevada described above. Both come from within the sagebrush belt. The subalpine-like conditions at Conway Summit are modified by the proximity of the desert areas with the extreme fluctuations in both diurnal and seasonal temperatures that characterize Great Basin climates. Plants from Conway Summit are taller and wider-leaved than the alpines when compared in the garden at Stanford. The population from Leevining, in turn, is taller than the Conway Summit population and later in flowering. Neither of these forms from the eastern slope of the Sierra Nevada has been grown in populations of 30 individuals at the Mather and Timberline transplant stations, but the data available from two plants of the Leevining race indicate that they develop much too slowly at Timberline to ripen seed, although their herbage is highly resistant to frost.

Latitudinal races. The evidence gained from experimental material collected from central California to Alaska indicates that latitudinal races are as diverse as the altitudinal races described above. For example, plants grown from seed collected by Mr. Malcolm Nobs at sea level on Kiska Island in the Aleutian chain have shorter stems, flower earlier, and are less winter-active than races from the coast of central California 15° farther south. Moreover, there are distinct altitudinal races on Kiska Island. Samples collected at four intervals between 500 and 1200 feet altitude are typically dwarf, being on the average less than 10 cm. high. These forms are winter-dormant, whereas those from below 500 feet are somewhat winter-active and taller, ranging up to 30 cm. The latter are more floriferous and partially winter-active at Stanford. The forms from both low and higher altitudes flower equally early, the winter-dormant ones catching up with the others because of their faster development, but at the expense of size. Individual variation within the Kiska populations from five different altitudes is marked and reflects a genic diversity comparable with that found in populations from the California transect.

Races of *Achillea millefolium* from Denmark at 55° N. latitude and from Lapland at 68° N. that were also included in these studies thrive and flower reasonably well at Stanford at 37° N. The Lapland race flowers earlier than the one from Denmark. Although these two races survive at the Timberline station, they are restricted to immature development consisting of a low, matlike mass of rosette leaves and underground rootstocks, no flowering stems appearing. Obviously, the Lapland race is physiologically very distinct from the alpines of the Sierras that grow vigorously and flower freely in the Timberline garden.

Cytology. In chromosome number, the Achilleas can be divided into two groups, the tetraploids with 18 pairs of chromosomes and the hexaploids with 27 pairs. Both appear to be multiples of hypothetical 9-paired forms that are probably now extinct. The forms of *A. millefolium* L. from northern Europe and those nearest to the west coast of North America, now classified as *A. borealis* Bong., all have 27 pairs, whereas the forms referred to *A. lanulosa* Nutt., from the Sierran Transition zone eastward to the Atlantic, have only 18 pairs. Professor W. E. Lawrence, of Oregon State College, has completed a survey of chromosome numbers in *Achillea,* and his findings reveal that parallel climatic races have evolved in both the 18- and the 27-paired species. In central Oregon the 18-chromosome *lanulosa* has reached the coast at one point, where, on exposed bluffs, it has developed a maritime race that closely mimics the maritime

race of the 27-paired species that ranges both north and south of that locality. Likewise, the 27-paired *borealis* on Kiska Island has developed an alpine race with morphological characteristics rather similar to those of the 18-chromosome alpines of the high Sierra Nevada belonging to *lanulosa*.

The selective effect of the environment. The studies on the climatic races of *Achillea* emphasize the close interrelation that exists between the genetic composition of natural populations and their environment. There is a climatic race peculiarly well fitted to survive in each major environment in the climatically diverse region across central California. On the basis of the statistical analysis of the performance of the 15 populations mentioned above from this transect, at least 10, possibly as many as 13, significantly distinct climatic races, or ecotypes, can be recognized, each fitting its particular environment in the transect. Their fitness is largely a genetically determined physiological capacity to meet the requirements of the environment.

The environments differ, among other things, in temperature and water supply, and especially in their seasonal cycles. The physiological requirements for a plant's success in any one of them are numerous and fairly exacting. Even small differences in climate, for example, an average temperature difference of only 1.9° C., and an average difference in frost-free growing season of only 48 days, such as are found on the west slope of the Sierra Nevada between Groveland and Mather, result in a detectable shift in the genetic composition of the natural populations found at these points.

Natural selection, however, is not absolutely rigid. Each local population is buffered against elimination through changes in its environment by two mechanisms: one is the physiological range of tolerance inherent in each individual, rendering sudden environmental changes less hazardous; the other is the supply of genetic diversity within the population, so that some individuals have a greater tolerance for changes in one direction, and other individuals a greater tolerance in other directions.

New forms arising through the recombination of races from different environments may be able to pioneer new horizons for the species. In *Achillea,* the timeless processes of evolution have produced a striking array of forms fitted to an exceptional variety of climates. This has been done without the incidental development of convenient taxonomic characters, so that the variations are very difficult to describe. The present experimental study of some of these forms has clarified the nature and extent of the variation observed in this species complex, and has made some progress in relating this diversity to environmental factors, but the evolutionary history of this complex is still unknown.

Poa Investigations

During 1946 approximately 100 new hybrids, involving 14 additional combinations, have been produced between strikingly different species of *Poa*. These are in addition to the 170 hybrid individuals of 19 combinations reported last year in Year Book No. 44, pages 73–78. A study of all these should provide a sound basis for judging the crossability of the bunchgrass Poas with members of the rhizome-producing *Pratenses* section of the genus, and their economic possibilities as range and forage grasses.

The successful production of first-generation hybrid plants, however, represents but the first step in exploring the genetic possibilities of these apomictic plants. At least two further steps are required before

a satisfactory working knowledge of these little-known groups of plants can be realized. One step is to find fertile F_1 plants that produce constant offspring by apomixis, and the other is to test their performance under different climatic conditions, such as at the Stanford, Mather, and Timberline stations. Progress along both these lines has already been made, and the information now on hand, although still incomplete, points toward unexpected but scientifically interesting complications.

When the work was undertaken it was expected that first-generation hybrid plants of apomictic species of *Poa* would reproduce apomictically, thereby providing true-breeding forms within one generation. During the current year, progenies of 43 F_1 individuals from 10 hybrid combinations were grown in the garden at Stanford. Of these, only 15 were reasonably constant, suggesting apomixis, whereas the 28 others segregated.

Previous investigators, using other plants, found that when sexual individuals were pollinated with apomictic ones, the resulting offspring were often apomictic. The earliest experiments of this nature were performed by Gregor Mendel and published in 1869. He crossed species of *Hieracium* and was perturbed to find that the first hybrid generation segregated, whereas later generations were constant—results quite opposite to those he had previously found in peas. Investigations during the present century by C. H. Ostenfeld and by O. Rosenberg established the apomictic nature of most species of *Hieracium*. More recently, Müntzing discovered that hybrids from sexual *Poa alpina* pollinated by apomictic *P. pratensis* reproduced sexually and segregated. In our crossings, only apomictic species of *Poa* were employed on both sides as parents, but this did not prevent two-thirds of the hybrids from becoming completely sexual. Basic knowledge of the genetics of apomictic species is still in the exploratory stages of development.

Sexual populations. The fertilities of the *Poa* hybrids producing segregating F_2 populations ranged from 0.5 to 90 per cent, but even the most sterile plant yielded 133 offspring, although only 23 of these were vigorous. In the most fertile combination 24 per cent of the seeds gave rise to vigorous offspring, but in the most sterile there was only one vigorous plant per 1000 seeds. The higher fertilities are unusual in hybrids between species belonging to taxonomically distinct sections of a genus, for strong genetic barriers usually exist between such plants. All sexual, segregating *Poa* hybrids, however, produced a considerable percentage of weak F_2 offspring in addition to many inviable seeds. The genetic barriers between the species of these two sections of *Poa* are therefore real, although they are only of an order comparable with those that usually separate species of one taxonomic section. This does not imply, however, that these two sections are unnatural. They constitute distinct morphological, biological, and evolutionary units. The unexpected degree of success in the intersectional hybrids here is probably connected with the high polyploidy in the species of both sections, whereby their chromosomes and genes have been duplicated. The disturbances in the genic balance produced by interspecific interchange have thus been to some extent buffered. Possibly also the tolerance is extended by the presence of one set of *pratensis* chromosomes in most of the hybrids, for there is probably no other species so tolerant of such a wide diversity of chromosome numbers (Year Book No. 44, p. 80).

The segregation observed in the offspring of the sexual hybrids is so profound that all the major characters marking these two sections of *Poa* are completely recom-

bined. Such characters include the presence or absence of hairs on the floral bracts, the character of the hairs, the length and shape of the ligule, the presence or absence of rhizomes, dormancy as compared with activity during the summer, and many others.

The segregation of each character involves a series of steps, suggesting that more than one pair of genes is responsible for each. Though the characters are thoroughly shuffled in the offspring, plants that approach each parental type have been segregated in small populations of only 240 individuals. Some of the recombinations are quite vigorous. The segregations are especially striking in the offspring of hybrids of the California bluegrass, *Poa scabrella,* crossed with various climatic races of the Kentucky bluegrass, *P. pratensis,* and provide interesting material for investigations in ecological genetics.

The hybridization of remotely related species often produces unexpected genetic effects. The commonly recognized Mendelian laws evidently operate by virtue of relatively delicate genetic balances that are easily upset when very different genomes are combined. In the present case the delicate mechanism that insures reproduction without fertilization has been disturbed, for many hybrids became sexual, although both parental species were apomictic. Apparently the condition of apomixis can be reversed in certain cases.

Apomictic populations. Fifteen hybrid individuals produced largely constant offspring and were probably apomictic. In fertility these 15 differed nearly as much as those with segregating offspring, for 5 came from plants with low seed fertilities of 0.5 to 10 per cent, and 4 from plants with fertilities between 33 and 50 per cent. The latter are about as fertile as wild apomictic forms of *Poa ampla* and *P. scabrella.* Four fairly vigorous F_1 plants were apomictic and developed constant progenies with reasonable vigor and fertility. All but one of these, however, appear to be somewhat less apomictic than most plants from the wild. From this it appears that the development of a successful apomictic strain such as those found in the wild involves a series of selections for vigor, fertility, and apomixis, in addition to a suitable combination of characteristics to fit it for its environment.

Even the wild apomicts in *Poa* are not completely constant, but segregate a small percentage of aberrant individuals that apparently arise sexually. These, however, are much weaker than the apomictic offspring, and are constantly eliminated in competition. The presence of a considerable percentage of aborted seed is evidence that the sexual process is still maintained, but the more vigorous apomictic offspring survive at the expense of the sexuals. The Poas are so prolific that the attainment of full fertility has not been necessary.

Progenies of only 44 of the 270 F_1 individuals on hand have thus far been tested for constancy. The untested hybrids are in various stages of maturity, only a few having flowered as yet.

Among the new hybrids that are being tested is a culture of 57 plants obtained from an outstanding form of *Poa ampla* from the Palouse Prairie, pollinated by a very rhizomatous form of *P. pratensis* from Mather. This variable F_1 hybrid population flowered for the first time this summer (1946) and contains many vigorous plants that grow well in the dry Stanford garden. Most are rhizomatous, rust-resistant, and summer-active like *pratensis,* but have the bluish foliage of *ampla.* In a population of this size there should be a fair chance of finding some vigorous and fertile apomictic plants.

A cross between a mountain form of *P. ampla* from eastern Idaho and an ever-

green, turfy form of *P. pratensis* from a coastal bluff in Oregon yielded a promising hybrid population of more than 50 plants. Many of the hybrids show excellent vigor, but they will not flower before next year.

Evolution and breeding procedure. The scientific aspects of the *Poa* program are closely linked with the practical, for an understanding of evolutionary processes is prerequisite to the synthesis of new forms suitable for agronomic purposes. It is evident from the foregoing that in the partially apomictic species of *Poa* highly selective processes precede the evolution of new forms. For this reason a fairly large initial stock of hybrids is necessary to render probable the securing of even one satisfactory strain that successfully fills a niche in a given environment, is reasonably constant, and is more productive than competing grasses.

The breeding problem consists not only in fitting the proper species together, but also in using the proper races of those species. The most vigorous parents do not always produce the most vigorous offspring in hybrid combinations. For example, a very productive strain of *pratensis* from northern Alberta does not produce as vigorous hybrids when crossed with a strain of *ampla* from southeastern Washington as does a less vigorous form of *pratensis* from Mather in the Sierra Nevada.

The exploratory crossings that have been made between the two contrasting groups of *Poa* species reveal something of the evolutionary pattern in the genus, and indicate the combinations that are most apt to be of promise for practical breeding. New possibilities have been opened and new problems raised through the discovery that partially apomictic plants may produce fully sexual offspring through interspecific crossing. The possibility of obtaining true-breeding strains through the doubling of the chromosomes of segregating hybrids is still unexplored. Another opportunity of promise lies in crossing different hybrids, thus adding as many as three or four different genomes in different combinations. Some vigorous triple hybrids have already arisen spontaneously in the garden at Stanford.

Transplant Stations

Cloned material of 155 first-generation hybrids and of representatives of 25 races and species of *Poa* not previously represented were transplanted to the mountain stations this spring. These are to be followed by the 100 seedling hybrids obtained this year, so that all may be tested in the three climatically very different gardens at Stanford, Mather, and Timberline. The *Poa* transplants have shown good initial survival and characteristically different reactions, but it will be several seasons before the full import of this experiment can be learned.

The Mather station was also utilized by Dr. Th. Dobzhansky, Research Associate of the Carnegie Institution from Columbia University, who continued his experiments on the genetics of native populations of *Drosophila.* Dr. Palmer Stockwell, of the Institute of Forest Genetics of the United States Forest Service, worked a short time at the Timberline station transplanting selected individuals of new pine hybrids to test their capacity to survive in the rigorous climate there.

PALEOBOTANY

RALPH W. CHANEY

The Mascall flora, from the John Day Basin of Oregon, is a significant example of the forest diversity which was prevalent in North America during most of the Tertiary period. Like other Miocene floras from the northern hemisphere, it is largely made up of modern genera of conifers and flowering plants. But in no part of the world today are all these genera found living together in a single forest, or even on the same continent. During the tens of millions of years since the Mascall flora was a living forest, many of its characteristic members have been eliminated. Forests now living in eastern Oregon are depauperate by comparison, and nowhere in the temperate zone is there an assemblage of trees of comparable variety. Analysis of the changes in forest composition during post-Miocene time, and consideration of the causes of these changes, not only throw light on the sequence of events in later earth history, but also provide a basis for interpreting modern vegetation.

The systematic study of the Mascall and other later Miocene floras of the Columbia Plateau, as recently completed by Drs. Axelrod and Chaney, brings the forms known from this region to a total of 188. Most of these show close resemblances to trees and shrubs still living, but following current paleobotanical procedure they are considered to be specifically distinct. One hundred and one genera are represented, and 52 families. With 4 exceptions all the families are now widely distributed in the northern hemisphere; 3 are confined to Asia, and 1 to North America. Most of the genera are likewise wide-ranging, but 14 are limited to Eurasia and 7 have been recorded only from North America; 1 genus is now represented in Australia, and 2 are limited to tropical America. The present-day distribution of species which are considered to represent the modern equivalents of Miocene plants shows concentration in three principal areas, eastern North America, western North America, and eastern Asia. The first of these areas has a summer-wet climate, and is the home of many broad-leafed deciduous trees; nearly one-half of the Miocene species appear to have living descendants there. In western North America, where conifers and broad-leafed evergreens show a response to summer-dry climate, living equivalents of over a third of the Miocene species have been recognized. A like portion of the fossil flora has descendants living in eastern Asia, where a summer-wet climate more like that of eastern America prevails. Many fossil species have modern equivalents in two or in all three of these regions.

We interpret this distribution of living plants to indicate a northern origin for their Tertiary ancestors. Occurrence of the same and similar fossil species in high-latitude Tertiary deposits older than Miocene gives strong support to this interpretation. The Eocene forests of the north, commonly known as the Arcto-Tertiary Flora, were diverse in composition, including genera which did not survive the southward migration into North America and Eurasia. Others reached the John Day Basin and adjacent areas during the Miocene, but have since become extinct in North America, although persisting in Asia. A few genera still live in the western hemisphere, but have become extinct in Eurasia. In western North America, the change to dry summers has eliminated many broad-leafed deciduous trees; they have survived on the eastern sides of the continents, where rain falls during the

summer. It seems clear that modern forest distribution in the northern hemisphere is the result of changes in topography and climate which have been taking place in late geologic time and are still continuing. Future changes may be expected further to limit or expand the ranges of the more sensitive species and to increase the number of extinct genera.

Work was begun on the Florissant flora of central Colorado by Harry D. MacGinitie nine years ago, and subsequently large collections were made. Previous work on this flora extends back as far as 1869, and has produced a list of published species totaling over 250. All these earlier studies have been revised in accordance with our greatly increased knowledge of the characters and distribution of related modern plants. As a result the original number of species has been reduced to approximately 105, and many of them have been assigned to different genera; about 20 new forms have been added from recent collections.

A large number of the existing relatives of the Florissant species occur in the region from central Texas southward along the Eastern Sierra Madre and westward to the central and southern plateau of Mexico. A small group of genera is now confined to the forests of eastern Asia, and others, of which *Sequoia* is an example, have survived only in western North America. The flora is made up of two types of vegetation: a rich mesic association of streamside genera such as *Acer, Juglans, Salix,* and *Zelkova,* and a group of small-leafed woody plants whose living representatives occupy the subhumid area of western Texas and southward. Great changes are indicated in both the climatic and the topographic setting of Colorado since the Oligocene epoch, when the Florissant flora was a living forest.

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DEPARTMENT OF EMBRYOLOGY

Baltimore, Maryland

GEORGE W. CORNER, *Director*

The year ending with June 1946 has been one of reorganization and realignment of work after the war period. Although this department, owing to the nature of its interests and experience, was not involved as a group in the war effort, nor were the quarters and equipment utilized for emergency purposes, yet the absence of two of the five senior investigators stationed in Baltimore, the distractions due to wartime conditions, and the various calls upon individuals for special tasks have greatly impeded the work. This state of affairs has happily come to an end and the laboratory is enthusiastically resuming the program set forth by the Director in the annual report for 1940–1941 (Year Book No. 40).

It has fortunately been possible to keep the quarters and equipment in reasonably good condition and even to begin the task of renewal and restoration. During the winter of 1945–1946 the long-needed repairs to the monkey quarters on the sixth floor of the laboratory were made. The worn-out original mastic floor of the inner rooms was replaced by tiling. The tiled floor of the paddock was repaired where necessary and new metal flashings were installed. The metal caging and all inside woodwork were repainted. The long time taken by the contractors, including delays caused by labor troubles, ran into the breeding season of the monkeys and forced postponement of most of the experimental work planned by the Director for the season.

A beginning was made on another necessary improvement, put off since 1941, that is to say, the installation of proper cages for small animals. A room used for rabbits was completely re-equipped with a bank of new caging of efficient modern type.

The Department library was augmented by several valuable sets of biochemical and physiological journals and the Index Catalogue of the Army Medical Library, which were transferred from the Nutrition Laboratory, Boston, when the latter was discontinued. These books are already proving very useful in connection with the newly reactivated physiological work.

PROGRAM OF INVESTIGATIONS

Dr. S. R. M. Reynolds has resumed research on the physiology of the pregnant uterus. He brought back from his service in the physiological section of the Army Air Forces valuable ideas for new apparatus to be used in recording small changes in pressure, blood flow, etc., based on the "strain gauges" used in aviation engineering. His preliminary experiments on blood flow in the pregnant uterus (rabbit) have already yielded valuable results which will be published shortly and reported in the next Year Book.

Arrangements are being made with the Department of Obstetrics of the Johns Hopkins University and Hospital for joint work on the physiology of the uterus in late pregnancy and in labor. The necessarily elaborate and expensive equipment is being provided partly from a grant in

the current budget of the Department for special equipment, and partly by the Department of Obstetrics.

Dr. L. B. Flexner is again actively at work on his prewar program of studies on placental transmission. Dr. Walter S. Wilde, formerly of Tulane University, has joined the Department staff and is at work with Dr. Flexner. One of their projects is the study of the transmission of phosphorus compounds from the mother to the embryo. Much of this work is necessarily carried on at the Department of Terrestrial Magnetism, where Dr. Dean B. Cowie is cooperating. Dr. Fleming, and more recently Dr. Tuve, new Director of that Department, have generously provided laboratory space and have made available the requisite products of the cyclotron. Some of the results are already in press and will be reported in the next Year Book.

Dr. C. H. Heuser, Curator of the Embryological Collection, has been engaged in the exacting care of the valuable new specimens received during the year and is continuing his intensive study of the earliest stages of development, which will ultimately appear in monographic form. His joint authorship, with the Director, of an article on human embryology for the *Encyclopaedia Britannica* will be discussed below.

The researches of Dr. R. K. Burns in experimental embryology, and of Dr. Margaret R. Lewis on tumors, are fully reported below under their special headings.

Dr. George L. Streeter continued actively during the year his extensive program of descriptive classification and arrangement of human embryos according to the successive stages of growth. This important undertaking, which was fully explained in Year Book No. 42, progresses steadily. The sections on stages XV to XVIII, analyzed in Year Book No. 44, are in press in the forthcoming volume 32 of the Contributions to Embryology. Work on several more sections is well under way, and will be reported when complete. In this enterprise all the resources of the Department for morphological work have been mobilized, including the services of the artist, the photographer, and the modelers, with results that promise to be exceedingly useful for a long time to come.

Dr. Washington Buño, professor of histology and embryology at the University of Montevideo, joined the Department on a Guggenheim fellowship and is engaged in studying abnormalities of early rhesus monkey embryos and in experimental investigations, with the Director, of the causes of embryonic maldevelopment.

A happy result of the termination of hostilities is the re-establishment of a group of part-time workers, young physicians, medical students, and other scientific workers using the laboratory's facilities for research. Dr. Elizabeth M. Ramsey has resumed her studies on the blood vessels of the placenta in the rhesus monkey, which it is hoped will soon be ready for publication. During the war, when much of the other work with the breeding monkeys was suspended, it was possible to prepare a number of placentas injected *in situ* and to store them for this work. Dr. E. Carl Sensenig, of Tulane University, and Dr. S. Culver Williams, of the University of Pennsylvania, spent several weeks each at the laboratory working with embryos in the Collection, studying the development of the vertebral column and of the dental primordia, respectively.

The collection of very early human embryos, by Drs. John Rock and Arthur T. Hertig of Boston, frequently mentioned in these reports, continues with the aid of a special appropriation through the Department of Embryology. As in previous years, several excellent specimens have been added.

Dr. Hertig reports that during the year he studied intensively twelve uteri from the operating rooms of Dr. Rock's service which it was thought might contain early embryos. From these, four specimens were obtained ranging from 8 to 13½ days of age. One of these (no. 8329) proved to be extremely abnormal, having no embryo, no cytotrophoblast, and no chorionic cavity. As has been frequently stated in these reports, abnormal embryos are as important for understanding of gestation as are normal embryos, provided always that sufficient normal examples are on hand for comparison. The addition through the work of Rock and Hertig of a considerable number of early pathological embryos to the Carnegie Collection, including this new specimen, is a valuable contribution to science. We look forward to a monographic publication on the specimens.

The other three new specimens, representing various stages of normal development in the second week, are of course also of great value.

The Department of Embryology is observing with great interest the continued work of Dr. Rock in obtaining fresh human ova from operative material and in attempting to bring about their fertilization *in vitro*. There are no positive findings to add to those reported last year. Although this work is not supported financially through the Department, it is necessarily conducted in association with the search for early embryos, and is being aided from time to time by the advisory services of Dr. Heuser and by provision of microphotographs.

THE EMBRYOLOGICAL COLLECTION

The Department's collection of human embryological material is by a considerable margin the largest in the world. The present time, when scientific institutions are taking stock after the disturbances and delays of war, is appropriate for a brief survey of the collection.

In 1913, when the founder of the Department, Dr. Franklin P. Mall, received his first grant from the Carnegie Institution for embryological research, he arranged to turn over to the incipient Department of Embryology his personal collection of human embryos, begun in 1887. This was already the world's largest special collection of the sort and it was fully organized for research purposes, having been continuously in use by Dr. Mall and colleagues and students. In Year Book No. 13 a tabular summary was published, showing that at the end of 1913 the collection numbered 813 specimens. The number of individual embryos now on hand, in 1946, is not easily ascertainable. The serial number has passed 8400, but many numbers refer to specimens other than embryos (e.g. placentas, ovaries, oviducts, etc.), and on the other hand a single number often refers to a group of specimens, such as fetuses received in a lot without individual records. It is estimated, however, that the collection includes specimens or records of not less than 10,000 individual human embryos and fetuses.

More useful to professional readers will be a statement of the number and classes of embryos which have been sectioned for microscopic study.

Grade 1. The core of the collection is a set of 441 embryos in complete serial sections selected because they are normal in form and in a superior state of preservation, fixation, and staining. These range from the age of 7½ days to about 4 months (80 mm. crown-rump length). The grade 1 specimens include 43 embryos in the pre-

somite stage, the larger part of which were contributed by Drs. John Rock and A. T. Hertig.

Grade 2. There are a few hundred embryos among the 1915 sets of serial sections in the "omnibus" collection. This classification includes most of the atypical and pathological embryos that have been sectioned, as well as the normally developed embryos of the second grade, i.e. useful but of less than perfect quality. It also includes specimens which are not embryonic, e.g. ovaries, oviducts, and other materials for the study of human reproduction.

Grade 3. Sometimes an embryo, when sectioned serially, proves to be in poor histological condition in spite of deceptively good external appearance. Sometimes the sectioning reveals unsuspected abnormalities or imperfections. The collection contains at present 71 such embryos which were, however, considered worth preserving for one reason or another.

Embryos from foreign laboratories. The collection contains useful material representing about a dozen embryos described in Europe, prominent in the embryological literature of a generation back. This material consists of tracings of sections or photographs, and of models made therefrom in the laboratory.

Professor Wilhelm His, Jr., a few years before World War II gave to the laboratory the scientific materials of his distinguished father, including a few of the human embryos described in Wilhelm His' papers and a small collection of other vertebrate embryos.

Development of the skeleton. A special collection to illustrate the development of ossification centers was begun by Dr. Mall and has been enlarged as occasion permitted. It now contains 125 human fetuses from the 7th to the 25th week, cleared to render them translucent and thus reveal the calcified parts of the bones. Many of these specimens were selectively stained with alizarin. The collection contains also a few vertebrate embryos of other species.

Primates of other species. The special collection of embryos of the rhesus monkey made by Drs. C. G. Hartman, G. L. Streeter, and C. H. Heuser and described in a monograph by Heuser and Streeter, Contributions to Embryology, vol. 29, 1941, comprises 74 superbly prepared embryos in complete serial section, including many very early specimens. In addition there are some dozens of larger embryos (not sectioned) and fetuses.

The collection contains the only known early embryos of the chimpanzee, 2 in number, both of the 11th day (see Year Book No. 39).

Through a special grant from the Carnegie Corporation of New York for the work of Dr. Joseph Gillman, of the University of the Witwatersrand, Johannesburg, South Africa, 6 very early embryos of the baboon have been obtained.

The howler monkey, *Allouatta,* is represented by 8 embryos.

Other animals. The collection includes 193 serially sectioned embryos of the domestic pig, including many of very early age. No special effort has been made to collect other species, and there are only about 50 embryos in all of the spider monkey (*Ateles*), sloth, chick, alligator, and such other species as may have been obtained by casual means.

Sectioning and orientation. It is the grade 1 material, of course, which provides the material used by the staff and by visiting investigators for morphological studies of the usual type. To provide the needful variety of aspect (i.e. planes of section) for microscopic study, selected embryos within any one age group have been cut respectively in the transverse, sagittal, and frontal planes. Transverse sections pre-

dominate. The thickness of the sections varies, according to the stage of the specimen, from 6 to 50 microns. By far the largest part of the material is stained with haematoxylin and counterstained with eosin or other acid dye. Long experience has shown that this familiar technique serves general needs better than any other. A number of the smaller embryos obtained before about 1930 were stained *in toto* with cochineal or carmine. A few have been prepared with Mallory's anilin blue–orange G–acid fuchsin connective-tissue stain.

Oriented bromide prints. Nearly 100 of the grade 1 human embryos and some of the chimpanzee, rhesus monkey, howler monkey, and sloth embryos have been made more fully utilizable by reproducing each section as an enlarged bromide projection print marked with orienting lines. The technique used at present is as follows. When the specimen is sectioned, a camera loaded with 35-mm. film is mounted vertically over the microtome, and the surface of the paraffin-celloidin block is photographed before each successive section is cut. The resulting photographs clearly reveal the external form of the section and the outline of the major internal structures. The frame or stop, of rectangular aperture, which cuts off the margin of the photograph bears four nicks, one at the middle of each of the four sides. These appear on each photograph and thus mark the orientation of each section before it was cut from the embryo. When the slides are stained and mounted, each section is projected onto a sheet of bromide paper and thus recorded as an enlarged highly detailed negative print; or the sections are photographed on film and positive enlargements made. Thereupon the corresponding photograph on the 35-mm. film is projected onto the bromide print so that the images coincide as accurately as possible, and then the two nicks on the top and bottom margins, and the two on the sides, are respectively connected by pencil lines ruled onto the print. These two lines in effect establish vertical planes through the specimen, and serve therefore to fix the orientation of each section with respect to its place in the embryo.

One hundred and eight portfolios of such oriented bromide prints, each representing a single specimen, are in the files of the collection. The prints can be used instead of the fragile slides for many purposes of embryological study. Their prime use, however, is in reconstruction of enlarged representations of the embryos, for which purpose the outline of the embryo, or of an internal structure, or whatever is to be modeled, is traced on the print and transferred to the wax plate by an underlying piece of carbon paper. For modeling on transparent plastic sheets, the sheet is simply laid over the photograph and a tracing made on the sheet.

Models. During its thirty-three years of operation the Department has constructed 795 three-dimensional wax and plaster models, representing enlarged embryos or organs, or parts thereof. Among these are several series of long-term value beyond the research for which they were made. The changing external form of the human embryo from the first week until the middle of gestation is fully represented by a long series of models. The development of the brain and sense organs is amply shown by models made in connection with Dr. Streeter's researches. The heart, the intestinal canal, and the female urinogenital system are also especially well represented.

During the past few years effective use has been made of reconstructions made by assembling sheets of transparent plastic on which successive sections have been drawn. The method has long been used with glass plates, but modern plastics are so trans-

parent as to permit seeing through scores of sheets. The resulting models, often of great beauty, are especially valuable when very delicate structures are to be reconstructed.

Photographs and drawings. The file of photographic negatives now numbers about 14,800. The normal external appearance of the human embryo at all stages of development, and of the membranes and placental attachment, is of course fully recorded. Many of the best specimens were photographed stereoscopically. A very large number of pictures of anomalous and pathological embryos of every type are also recorded. Thousands of photographs of individual sections, made to illustrate specific researches, are in the files and are frequently used for study and to illustrate publications.

Housing. The sectioned embryos, bromide prints, and negatives are kept in a fireproof vault, especially constructed for the purpose.

Records. The collection is fully indexed so that the clinical histories and all descriptive notes, drawings, and photographs can be quickly located. A set of cross indexes enables the rapid selection of special material. For example, all the embryos, or all the grade 1 specimens, of a given age group, or all those sectioned in a given plane, may be selected at once from the classified index. Multiple births, anomalies, etc. are separately listed. A contributor's file indexes the names of the physicians who have donated specimens.

Use of the collection. The Carnegie Embryological Collection is primarily research material for the use of the departmental staff. Accredited scientific visitors are, however, welcomed as fully as is permitted by the limited accommodations, and are given full use of such material as may be needed for their work. Every year there are several such visitors, ranging from persons who stay only a day to some who remain for weeks or months and undertake extensive research. Such work by visitors forms a useful addition to the output of the Department.

Loans of specimens for use outside the laboratory are very seldom made. The more precious specimens, including the presomite stages and other young embryos, are never taken from the laboratory. By special arrangement in individual cases, older embryos of stages well represented in the collection are sometimes lent one or two at a time to responsible investigators in established laboratories in the United States. Neither the original slides nor the bromides are permitted to leave the laboratory when they are needed by the staff. It is the Department's policy, when a loan is requested, to ask the investigator to visit the laboratory long enough to familiarize himself with the collection. Such a visit makes the use of the material much more effective on the part of experienced embryologists, and sometimes averts waste of time by revealing impracticable plans of inexperienced workers.

Cooperation. Not infrequently a specimen of special value is contributed by a physician who is favorably situated to study and publish it. In such cases the donor is encouraged to do the research himself. Models, photographs, and drawings may be provided by the Department. A number of excellent articles in the Contributions have originated in this way, and needless to say the policy has made many good friends for the laboratory, besides generally securing the permanent deposit of the specimen.

It must be pointed out, however, that progress in descriptive embryology has gone so far that individual human embryos, except those of the second week of development and any of the first week that may ultimately be obtained, are no

longer so rare as to call for individual monographic publication. The time has come when new information must be gained by comparison of stages and by assemblage of data from groups of specimens.

Sources of the material. The human embryos and fetuses in the working collection have mostly been donated by the physicians and surgeons of the United States. In the earlier years of the Department the medical profession was repeatedly circularized with an appeal for specimens, to which a generous response was made. The Departmental "donor file" contains the names of hundreds of doctors in all parts of the country who have thus contributed to science. A copy of each annual report from these Year Books is mailed to all physicians who have contributed specimens in recent years.

The continued accumulation of human embryos of all ages, even of those stages of which the general structure is well known, remains an important duty of the Department, because embryonic morphology has passed from the era of individual description to a phase in which group study, comparison, and statistical analysis are essential to progress. There is, however, particular need for specially obtained and selected specimens illustrating the imperfectly known early stages, and for fresh or specially preserved organs and tissues of older stages required for individual researches. The Department therefore tends to rely upon its more constant friends among the gynecologists and obstetricians, actively cultivating the cooperation of those whose opportunities and experience make their contributions especially valuable. The collecting of early embryos by Drs. John Rock and Arthur T. Hertig of Boston, in close cooperation with the Department and aided by a special fund, has frequently been mentioned in these annual reports. When need arises for fresh fetal material, the large and active clinics of the Baltimore area can be relied upon to watch for it as requested by the Department.

PUBLISHED RESEARCH

The Effect of Androgens upon the Embryonic Urinogenital System

The work of Dr. R. K. Burns, in which the development of the reproductive organs is being studied experimentally, continues to yield valuable results. In these experiments, the opossum is used because of the opportunity it affords to administer hormones to the young animal in the brood pouch, while it is still in an embryonic condition.

Dr. Burns has reported previously that development of the sex ducts in young opossums is readily modified by the administration of steroid hormones. In relatively low doses these hormones behave in a "sex-specific" manner, but when large doses are given, both male hormone (androgen) and female (estrogen) tend to induce simultaneous development of the derivatives of both the Müllerian and the Wolffian ducts, in individuals of either sex. The outcome, as regards the sex ducts, is almost perfect morphological hermaphroditism. Dr. Burns has previously described the gross effects of such treatment, and during the past year has reported on the histological features. His paper deals only with the effects of androgens.

The following résumé of the results is in great part from the summary prepared by Dr. Burns.

In young opossums of either sex, large doses of androgen administered during the

period of sex differentiation induce precocious development of both sex ducts to a striking degree. In spite of unusually close topographical relations, the two duct systems differentiate simultaneously and apparently in complete independence. Experimentally produced "intersexes" of this type have highly differentiated epididymides and vasa deferentia, with patent communications at all levels; at the same time the female genital tract is represented by oviducts with wide ostia, large uteri, and (in most females) highly developed vaginae. Histologically there is hypertrophy of both the epithelial and the mesenchymal constituents of the various organs.

These effects show considerable variation, quantitatively, with respect to dosage, age, and the sex constitution of the subject. Growth of both male and female genital tracts diminishes with decreasing dosage, as would be expected; but the most significant finding from this standpoint is the demonstration of a dosage level (5–10 gammas of testosterone propionate per day) at which the Müllerian duct ceases to respond, whereas all the derivatives of the male duct still show marked hypertrophic reactions. At all higher dosages constant differences in growth capacity, correlated with sex constitution, are observed. The general principle emerges that, under the influence of androgen, derivatives of the male duct are always more highly developed in male subjects than are the homologous structures in genetic females; conversely, the paradoxical growth of Müllerian duct derivatives in both sexes, resulting from large doses of androgen, is always much greater in female subjects. This constant difference in reactivity is evidently prescribed in the sex constitution of the individual.

Other sex differences of a more specific kind are found in the reactions of certain local structures or organs. These differences are also strongly predetermined in the normal pattern of development. As an example, in normal male opossums the vaginal region of the Müllerian duct degenerates very early, or is aborted before it establishes definite contact with the urinogenital sinus. It is found, in the face of this very strong predisposition, that even the largest doses of hormone fail to induce survival and development of vaginal canals in males, although uteri, oviducts, and ostia are very strongly hypertrophied in such individuals. Again, in female subjects in which full vaginal development would normally occur, this same region of the Müllerian duct is especially subject to inhibition, and one vaginal canal, or occasionally both, may be suppressed, in the presence of a great hypertrophy of the remainder of the female tract.

The ostium of the Müllerian duct holds a similar special status, but its case is less extreme. In normal males the ostium undergoes involution relatively early, as is pointed out in the brief description of normal development. At higher dosages it is preserved and well developed in most males, but at lower dosage levels its survival is greatly reduced, although the adjacent segment of the oviduct is always much enlarged, and even strongly convoluted. On the other hand, suppression of the ostium has not been thus far recorded in a female.

It appears from these circumstances that such exceptional reactions of regional structures, although out of line with the general result, are not merely eccentric. In male subjects those Müllerian duct derivatives which are least susceptible of stimulation experimentally are those which undergo involution first in normal development; and the homologous structures in females are found to be more readily inhibited by androgen.

All these findings point to the existence not only of different thresholds of response for different embryonic sex rudiments (even when derived from different regions of the same structure—the primitive sex duct), but to further differences in threshold, or at any rate in growth capacity, conditioned by sex constitution. Differences of the second type mean, concretely, that the same embryonic structures in subjects of different sex (sex homologues), though reacting alike, qualitatively, under hormonal stimulation, yet exhibit constant differences in growth capacity under identical conditions of treatment.

The suppression of the vaginal region of the Müllerian duct in some females is a clear-cut example of the inhibition by androgen of a major structure, a result which may be compared with the total suppression of the prostate gland by estrogen (Burns, 1942), with the difference that it is not of universal occurrence, even with large dosages, but is found in about 50 per cent of cases, counting the two sides of the individual independently. The vaginal canal, however, is either present and well developed, or lacking entirely, and it may be present on one side and absent on the other. This situation, suggesting an "all or none" type of response, again resembles the inhibition of the prostate by estrogen, in indicating that the survival and rapid differentiation of the organ, or its total elimination, is determined very early in development, and within a brief span of time. Presumably there is a critical stage beyond which, if the structure survives at all, its development is assured; otherwise we should expect to encounter atypical structures in varying stages of development or involution. It is suggested that the higher dosages employed are close to the critical level for suppression of vaginal differentiation in females, and that further experimentation in the case of the prostate might also reveal a level at which inhibition is an "all or none" phenomenon.

Dr. Burns points out that stimulation of the heterologous sex duct by sex hormones in the opossum thus far has no parallel in other mammals used in similar experiments. However, owing to necessarily different methods of administering the hormone to embryos of higher mammals *in utero,* the relation of dosage to the effects achieved is not comparable in the various experimental studies. In rats, mice, and guinea pigs studied by other workers, only the females have been made "intersexual" by virtue of the survival of differentiation in the female of all Wolffian duct derivatives. Males are not affected beyond some slight acceleration of normal development. It is apparent that the relative importance of species differences (as laid down in the organization of the embryonic rudiments) and of methods and time of administration of the hormone, dosage-threshold balances, relative rates of growth, etc. must be worked out before satisfactory generalizations can be made.

Oxidative Enzymes in the Fetal Brain

Dr. Louis B. Flexner has continued his series of observations, begun almost ten years ago, on the correlation between morphological, physiological, and biochemical changes occurring in organs during their prenatal development. The five previous papers of the series, written by Dr. Flexner and various colleagues and based on work done in the Johns Hopkins Department of Anatomy and in the Department of Embryology of the Carnegie Institution, have been reported in earlier Year Books. During the past year Dr. Flexner, with Dr. Josefa B. Flexner, representing the Poliomyelitis Research Center of the School of Hygiene, Johns Hopkins University, has published a sixth article of

the series. This deals with changes in the metabolic functions of the brain-cortex tissue as it passes through the successive stages of embryonic development. The specific topic of the work is the changing rate of activity of the important enzyme *succinic dehydrogenase* and of the complete system in which that enzyme takes part, known as the *succinoxidase system*. In this particular enzyme system, one of several that control oxygen metabolism in different organs, the succinic dehydrogenase acts first to free hydrogen from a particular source, namely *succinic acid*, an organic substance derived ultimately from the carbohydrates of the food, which is readily available in the tissues. The hydrogen thus freed then acts (either directly, or indirectly by intermediate steps not yet well understood) to reduce *cytochrome*, one of the so-called respiratory pigments found in animal tissues. Another enzyme, *cytochrome oxidase*, thereupon activates oxygen which serves to oxidize the reduced cytochrome. By such a chain reaction the succinate is oxidized; hence the term *succinoxidase* system is used to denominate the total mechanism. As has already been mentioned, this is one of several well known chemical processes by which various metabolites (i.e., foodstuffs and their breakdown products made available by digestion) are oxidized, that is to say burned, thus producing heat or other forms of energy for use in life and growth.

The material for the present study consisted of brains of fetal pigs obtained from a slaughterhouse. The measurements, described in detail in the article, were made by placing the brain tissue in a gastight apparatus (Warburg apparatus) with a supply of succinate and of oxygen upon which to act, and with more than sufficient amounts of cytochrome and of cytochrome oxidase. The resultant rate of oxygen consumption is limited by the amount of dehydrogenase present and serves as a measure of that amount. The activity of the whole succinoxidase system was measured by placing the brain tissue in a Warburg vessel with a supply of sodium succinate and oxygen and determining the amount of oxygen used up.

The results show that succinoxidase activity in the brain cortex is absent or at least very low during approximately the first half of prenatal life and then rapidly increases until the time of birth, when it is equal to that found in the adult. The level of succinic dehydrogenase, which, as explained above, is one of the essential factors in the chain of reactions, is also rather low during the first half of gestation, amounting to about 35 per cent of the value found in the adult. It too rises rapidly to full value at the time of birth. There is, however, enough dehydrogenase even in the earlier half of the developmental period to permit ample succinoxidase activity. The low activity in the earlier stage is explained by a low concentration of cytochrome c. Such a low concentration of cytochrome c has already been shown to exist at this time, in an earlier paper of the series (Flexner, Flexner, and Straus, 1941, reviewed in Year Book No. 41).

In the same contribution of 1941 it was shown that there are two critical periods in the structural development of the pig's brain cortex as revealed by the microscope. The first is at about the 55th to the 61st day of gestation and is characterized by rapid increase in size of the primitive nerve cells (neuroblasts), by a change in form of the cells from spindle shape to round, and by an increase of the Nissl substance in the cytoplasm. Another critical period, occurring between 90 and 108 days (i.e., relatively late in the prenatal period), is characterized by renewed rapid cell growth and by a change in the form and distribution of the Nissl substance to the state

found in mature nerve cells. The rise of succinic dehydrogenase activity revealed by the present observations occurs between the two critical periods of structural differentiation.

Strain Differences in Response to Carcinogenic Agents

Dr. Margaret R. Lewis, a member of our departmental staff working at the Wistar Institute of Anatomy and Biology in Philadelphia, continues her program of studies on the biology of malignant tumors. In our last report (Year Book No. 44) her experiments, done with Dr. Helen Dean King, on the transplantability of tumors in rats of many strains were discussed. During the past year a further contribution has been published, in which the investigators extended their study of two particular facts which appeared in the earlier experiments. In the first place, there is a sex difference in the rate of development of induced tumors. When rats of both sexes were suitably injected with a carcinogenic hydrocarbon (dibenzanthracene, benzpyrene, or methylcholanthrene), all developed sarcomas at the site of injection. Thirty-seven litters of rats were used. In all but 3, primary induced sarcomas arose earlier in males than in females. This fact may be associated with the known relative acceleration of general bodily growth in males of this species as compared with females.

In the second place, primary induced tumors in gray Norway rats grew much more slowly than did those induced in King inbred albinos and in Wistar albinos, and in rats of various other strains. This finding is tentatively set down as another of the numerous differences in genetic constitution of the rats of the various strains used. A kindred observation is that sarcomata induced in the subcutaneous tissue of the King inbred albino rats were accompanied by lung neoplasms, whereas those induced in Wistar albino rats did not affect the lungs of their host.

Induction of Immunity against Malignant Tumors

Dr. Margaret R. Lewis, jointly with Dr. Paul M. Aptekman and Dr. Helen Dean King, has been working for several years on the effects of extracts of malignant tumors. Year Book No. 43 included a report of their finding an extract of rat sarcomata which in some instances caused the development of a sarcoma when injected into rats. In the course of the same work these investigators obtained an alcohol-soluble fraction that inhibited the growth of grafted tumors and conferred immunity from growth of subsequently grafted tumors in a large percentage of treated rats. To bring about such a result it was necessary to inject the extract directly into the tumor.

These experiments have now been expanded in the hope of reaching a clearer understanding of the process of immunity. It must be stated first that grafts of tumors that originated in inbred albino rats were implanted into more than 5000 rats of their own strain of origin. Every one grew and not one regressed. This large group serves as a background control upon subsequent results. Tumors were ground up and extracted with 95 per cent alcohol. The extract was concentrated by distillation. Fifty-eight inbred rats were implanted with a tumor that originated in their own strain. After the graft had grown to a moderate size, each tumor was injected repeatedly with the concentrate. In 56 of the 58 rats the tumors were destroyed and the site healed with only a slight scar. Twenty-four of the healed rats were observed for about one year. They remained free from tumors. Thirty-two of the healed

rats were reimplanted with tumors of the same kind. Twenty-five (78 per cent) were found to be immune to two or three subsequent grafts. Twenty-five of these proved immune rats were implanted with grafts of other tumors that arose in their strain. Sixty per cent of them were now also immune to the growth of these tumors of other types. Extracts prepared from beef muscle and from normal rat tissue did not destroy the tumors, nor did solutions containing alcohol in concentration similar to that of the concentrate. The hosts of tumors treated with control solutions remained susceptible to the growth of grafts of the same kind of tumors that had been treated and also of other tumors that had originated in their strains.

These are apparently the first experiments in which the injection into tumors of a substance such as the concentrate used here brought about destruction of a tumor that arose in rats of its own inbred strain, and was followed by the establishment of immunity against tumor growth in the majority of treated rats.

Retardation of Sarcomata by a Dyestuff

In Year Book No. 44 mention was made of experiments by Mr. Ivor Cornman and by Dr. M. R. Lewis on the action of penicillin upon tumor cells in tissue culture. In brief, the finding was that retardative effects of certain preparations of penicillin upon tumor cells were due, not to the penicillin itself, but to a contaminating substance of unknown nature. The substance was yellow, and therefore Dr. Lewis began tests of various pigments found in molds and other plants. The search led on to synthetic pigments (chemical dyes), and ultimately to one particular family of anilin dyes, the Nile blues. The experiments now reported were done by Dr. M. R. Lewis, using the facilities of the Wistar Institute, in association with Drs. Henry A. Sloviter and Philip P. Goland, of the Harrison Department of Surgical Research and the Department of Neurosurgery of the University of Pennsylvania. A large number of samples of dyes of the Nile blue series was collected and the dyes were fed to mice bearing growing sarcoma grafts. The mice were from two inbred strains in which a grafted sarcoma invariably grows, when implanted into a mouse of the strain in which it arose. In addition to the Nile blue dyes, both commercial and specially synthetized, a series of derivatives known as oxazones was prepared, because it is known that the presence of oxazones in the solutions of dye salts is important in histological staining with dyes of the Nile blue type.

The result of the feeding experiments was that every sample of Nile blue and the corresponding oxazones stained the tumors a diffuse blue and retarded their growth. Some of the tumors were held back to one-tenth and even one-twentieth of the size of tumors in control mice. With some of the samples the tumors were almost destroyed. In even the smallest retarded tumors, however, microscopic examination showed viable tumor cells in the blue-stained zone around the unstained dead parts of the graft. Grafts from such surviving tumor tissue, when transplanted to fresh mice, grew much more slowly than those from the medium-sized tumors.

There are a few previous indications in the literature that certain dyestuffs inhibit the growth of tumors. The present experiments contribute a very clear-cut addition to knowledge on the subject.

A Human Embryo about Four Days Old

At the 1946 meeting of the American Association of Anatomists Dr. Arthur T. Hertig described a human embryo obtained

about 4 days after ovulation, which he deposited in the Carnegie Collection last year and which was perfectly sectioned by Dr. C. H. Heuser. It is in the stage of segmentation, consisting of several cells. The presence of a small space among the cells probably indicates the beginning of a segmentation cavity, for which reason Dr. Hertig in his paper (see bibliography) termed the embryo a blastula. Part of the zona pellucida, torn open, is present over the cell mass. Because of inequality of size of the cells and especially because some of the cells have more than one nucleus, this embryo is believed to be pathological. Great interest attaches to it, in any case, as the first and only authenticated human embryo yet obtained before implantation.

Reproductive Cycle of the Baboon

In Year Book No. 44 mention was made of an arrangement by which a fund granted to this Department by the Trustees of the Carnegie Corporation of New York from their British Dominions and Colonies Fund has been put at the disposal of Dr. Joseph Gillman, of the University of the Witwatersrand, Johannesburg, South Africa, for study of the physiology of reproduction in the baboon, and for the collection of embryos of that species. It has been repeatedly mentioned in these reports that early embryos of mammals cannot be obtained without intensive knowledge of the reproductive habits and cycles of the species. Inevitably, therefore, research in embryology contributes to study of the cycle, and vice versa. This truism has been verified again by the publication of an extensive article on reproduction in the baboon, by Dr. Gillman and Miss Christine Gilbert. The work has been in progress for several years and has received support from various quarters. In its later phases it has been aided by the grant just mentioned.

Some of the findings may be summarized here. The species studied is the Chacma baboon (*Papio porcarius,* recently called *Papio ursinus*). The average length of 507 menstrual intervals, with a range of 17 to 328 days, was 39.63 days. After exclusion of cycles considered abnormal, the average (404 cycles) was 35.61 ± 0.158 days, with a range of 29 to 42 days. In this animal there is a periodic turgescence of the perineum related to the cycle. By observing and measuring this turgescence, the menstrual cycle can be subdivided into two main phases, of turgescence and deturgescence respectively. The first phase averages (in cycles considered within normal range) about 19.5, the latter phase about 16 days. The phase of deturgescence is less variable and less frequently disturbed by experimental procedures than the phase of turgescence. The phase of turgescence is basically under the influence of estrogenic hormone; that of deturgescence is caused in part by substances akin to the corpus luteum hormone, progesterone. Irregularities of the menstrual cycle are to a considerable degree explainable in terms of the physiology of the normal cycle and point toward better understanding of the menstrual cycle and its disorders in women.

DIFFUSION AND POPULARIZATION OF RESULTS

At the request of the editor of the *Encyclopaedia Britannica,* Dr. Heuser and Dr. Corner prepared an article on human embryology which will appear in future printings of the current edition. This article, which amounts to 6000 words space, inclusive of text figures, deals with those features of human development which are of most interest to the general reader, or which are peculiar to man and the primates

and are therefore not covered by the other articles in the *Encyclopaedia,* e.g. that on vertebrate embryology in general. Special attention is given to the early stages of man, implantation, rate of development, changes in external form, multiple births, and pathology of the embryo. Mr. Didusch, the Department's illustrator, contributed a very instructive set of text figures from sketches by the authors. A group of photographs mostly by Mr. Reather, illustrating external form at successive stages of development, was selected by Dr. Heuser to accompany the article.

Dr. Louis B. Flexner is contributing to the *Encyclopaedia Britannica* an article on the meninges and cerebrospinal fluid which will be part of the sequence on the nervous system in that work.

Dr. Flexner contributed to the *Annual Review of Physiology* a chapter on "Developmental physiology," in which he reviewed the work of the past few years on all phases of physiology of the embryo and of the placenta.

Dr. S. R. M. Reynolds has published a lecture on "Human engineering in the Army Air Forces," based on his work and experience during the war. It is a review of the problems of applied physiology that were met with in the effort to give bodily protection to air personnel in flight, in crashes, and when accidentally driven to the ground or to the sea.

Dr. Corner lectured during the year at Wells College, Aurora, New York, and at Goucher College, Baltimore, on the embryology of human twinning and other multiple births. The Carnegie Collection of human embryos contains several of the earliest known human twin embryos, the earliest known human double monster ("Siamese twins"), and other specimens relevant to this lecture.

Dr. Burns, Dr. Heuser, Dr. Flexner, and Dr. Corner each gave one lecture, by invitation, to the students of the Johns Hopkins Medical School.

The new popular science magazine, *Science Illustrated,* featured in its fourth number (July 1946) a series of photographs of human embryos made in the course of routine work by the Department's photographer, Chester F. Reather. Most of these pictures have appeared in scientific publications but have not previously been available to readers of popular magazines. The captions, which were written by a staff writer of *Science Illustrated,* were submitted for approval before publication. Though popular in style, they are sufficiently technical to interest students of biology at high-school and college level. The article is accompanied by a photograph of Mr. Reather at work.

The older members of the Departmental group entered upon their studies in embryology at a time when all reference to human sex and reproduction was taboo in polite conversation and in popular journals. The public attitude has so far changed that it is now quite proper to give a semipopular lecture on embryology before a general audience at a woman's college and even to print pictures of embryos in a family magazine. So general is the desire, outside as well as within academic circles, to understand human reproduction, that a member of the secretarial staff of the Department had three requests during the year, from acquaintances who knew of his work, to give talks to Y.M.C.A. and church groups. This is a striking and healthy phenomenon. It threatens, however, to make unforeseen demands upon the staff. The Department has been called upon during this past year, for example, to receive visits from the biology classes of two local preparatory schools and of a teachers college in a neighboring state. Each of these visits took two or three hours of an investigator's time. Another effect of the

change in viewpoint is a demand, as yet relatively small but apparently growing, for advice to physicians and also to laymen by correspondence, about personal problems relating to reproduction. These burdens cannot lightly be passed to others. There are not, as in astronomy or chemistry, and even in other fields of biology, numerous institutions similarly equipped to help answer questions, furnish authentic pictures, and demonstrate technical methods. If this demand for service through other means than research in the strict sense continues to grow, such service will have to be systematized and limited as wisely as possible. It is to be hoped that ways can always be found to keep the intelligent public aware of what is going on in the laboratory.

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DEPARTMENT OF GENETICS

Cold Spring Harbor, Long Island, New York

M. DEMEREC, *Director*

Changes in the staff during the past few years have had an appreciable effect on the general scope of research at the Department. This was particularly apparent last year, when the work carried on by Riddle's group was discontinued following his retirement from service in the Institution. Moreover, although our participation in war research was mainly along the lines of our regular research, the war also had a considerable indirect effect on our work. In view of such changes and modifications, we welcomed Dr. Bush's request for the formulation of a plan for the future research program of the Department of Genetics. During the first half of this year, the members of the staff spent much time in conferences and discussions concerning the present status of genetic research and the role our Department is playing now and may play in the future. The outcome of these considerations was a 68-page "Outline of a proposed program of research for the Department of Genetics," submitted to Dr. Bush. In this outline the main emphasis was placed on discussion of the broad research aims of the Department as a whole, and of the specific programs of individual members of the staff; but in addition the questions of physical plant, equipment, personnel, and relations with the Biological Laboratory were considered.

The research of the Department in the future is visualized as focusing around a central theme, with each member of the staff working on a problem that forms part of this theme. The problems of individual members may or may not overlap, but each member should have a special interest in the field covered by the work of the whole group. It is proposed to focus research on broadly conceived studies of the gene, the central aim being "the elucidation of fundamental problems concerning the nature and action of genic substances."

In considering the question of personnel, the importance of temporary appointments was emphasized. In this way, young people can be brought to the Department as fellows, and established scientists as guests. The desirability of cooperation with other institutions and with the other departments of our own Institution was also pointed out.

During the past year, in the course of the study being carried on by McClintock with a view to inducing new mutants in maize, a number of unexpected and rare types of unstable mutant appeared in the cultures, along with the expected types of new mutant. Fourteen new mutants showing variegation or mosaicism have been isolated, although more appeared in these cultures. Preliminary study of six of these unstable mutants has suggested that a basic phenomenon, common to all, underlies the mutational changes. It involves the control of the rates of mutation of the particular gene. In all six cases, a number of different rates of mutation were observed among the different individuals or within well defined sectors of a single individual. Factors that control the different rates of mutation may be traced to an event that occurs in a single progenitor cell, or—more probably, as some of the evidence suggests—during a single mitosis. One of the

variegating types is unique. It involves the production of a break in one of the chromosomes of the complement. This break occurs at a particular locus in the chromosome, producing a deficient centric chromosome and an acentric fragment that is subsequently eliminated from the nucleus during a mitosis. A single break in a somatic nucleus in this case corresponds to a single gene mutation in the other cases.

Stephens has found that the early death of the hybrid embryos that invariably occurs when two particular species of cotton are crossed is not due to zygotic inviability but is associated with endosperm failure. Attempts to culture immature embryos at a sufficiently early stage have so far been unsuccessful. Stephens has investigated chemically a case of pseudoallelism in the anthocyanin series of Asiatic cottons. The results obtained so far indicate that two neighboring loci have arisen by duplication, since the genes present at these loci control closely similar chemical reactions which are necessary steps in the synthesis of anthocyanin. They act, however, on distinct though chemically similar substrates. This suggests either that duplication *per se* may result in increased specificity, or, alternatively, that genes after duplication may diverge in function. A probable second case of pseudoallelism in the "Crinkle-Contorta" series in New World cottons, which appears to be associated with indole synthesis in the plant, is being investigated.

Work carried on in MacDowell's laboratory by Biesele has indicated that chromosome size in both normal and neoplastic cells of mice is not a function of the number of longitudinal structural entities (chromatids), so far as could be detected in uncoiled chromosomes by means of the light microscope, but is related to the varying amount of pepsin-digestible protein and perhaps of other constituents of the chromosomes, in accordance with the functional state of the cell. Previously, the cells of the transplanted leukemias studied in this laboratory have been described as morphologically parallel to various stages in the development of normal lymphocytes, but Miller has discovered an entirely unparalleled cellular feature of leukemic blood. Anucleate structures of living cytoplasm appear in the blood of all the current transmission lines as well as in cases of spontaneous leukemia; their frequency varies according to the line, from 3 to 39 per 100 white cells. The observations support the interpretation that these imperfect cells are formed from leukemic lymphocytes by a process of nuclear disintegration. A single, moderately dilute dose of line-L leukemia has recently been found not only to permit survival of the host, but also to confer immunity against a standard dose. Using this unique experimental material, Gasić has demonstrated that the presence of the adrenal gland and the involution of the thymus are not necessary for the successful functioning of this immunity.

The discovery by Kaufmann that near infrared radiation is effective in sensitizing the chromosomes of the spermatozoon of *Drosophila melanogaster* to breakage by X-rays has led to efforts to determine the effect of the supplementary radiation on the frequency of lethal mutations. Preliminary experiments indicate, however, that there is no marked difference between the percentages of lethal mutations induced in flies receiving both near infrared radiation and X-rays and in those receiving only X-rays. It appears, therefore, that near infrared radiation is not effective in influencing the frequency of X-ray-induced recessive lethals. It had also been found in the earlier study that the supplementary treatment does not modify greatly the frequency of dominant-lethal changes.

The studies being undertaken by Kaufmann and McDonald on the organization

of the chromosome require the use of purified crystalline enzymes. Several of the enzymes have been prepared in recent months, and are now being assayed by McDonald for purity and specific activity.

Th. Dobzhansky, Professor of Zoology at Columbia University and a Research Associate of the Institution, has developed his studies on the rapid evolutionary changes taking place in certain natural populations of the fly *Drosophila pseudoobscura.* These changes, involving types of chromosomes, were previously known to have a cyclic character, linked with the succession of the year's seasons; it is now known that in some localities there occur in addition more sustained trends of change, lasting for at least several years. The cyclic changes have been experimentally shown to be caused by natural selection. These experiments involve setting up artificial populations of the fly in specially constructed "population cages." The remarkable fact disclosed by these experiments is that the genetic structure most highly favored in the struggle for existence is that carrying chromosomes of different types (structural heterozygotes), whereas flies having two chromosomes of the same type (structural homozygotes) are discriminated against by natural selection. This circumstance is very important in the life of the species, for it causes natural populations to consist of permanent mixtures of from several to many chromosomal types.

The technique developed by Demerec for treating sperm of *Drosophila* males with various chemicals has proved successful. Of nineteen chemicals tested, one—methyl-*bis*(betachloroethyl)amine, or nitrogen mustard—induced a considerable number of sex-linked lethals. According to this technique, males are kept in an atmosphere containing an aerosol of aqueous solution of the chemical. Presumably, very fine aerosol droplets are able to reach the sperm through the numerous tracheae of the testes.

The genetic aspects of bacterial resistance have been studied by Demerec, Luria, Oakberg, and Witkin. Using *Escherichia* and *Staphylococcus,* Demerec has found that resistance to streptomycin originates through a process of mutation. As was previously found in the case of penicillin, highly resistant strains may be developed in several steps; but in the case of streptomycin they may also develop in one step—an undesirable property from the clinical standpoint. Studying resistance to penicillin in *Staphylococcus,* Luria has obtained additional evidence of the lack of correlation between resistance to penicillin and capacity to produce the penicillin-destroying enzyme penicillinase. Oakberg and Luria have concluded that genetically determined changes in a number of different metabolic processes of the bacterial cell result in increased resistance to sulfa drugs. Witkin has found that mutants in *Escherichia* having higher resistance to ultraviolet rays and X-rays occur with a frequency of about 1×10^{-5} per bacterium per generation, and also that this mutation rate may be increased by ultraviolet radiation.

Demerec and Latarjet, investigating the relation between various doses of ultraviolet rays and X-rays and the frequency of induced mutations in *Escherichia,* have concluded that the possible site of mutational change is inside the bacterium; that the change is complex, requiring, as a primary step, the absorption of radiant energy by several molecules; and that the volume within which the change occurs is not larger than might be affected by a single cluster of ionizations. After studying the effect of ultraviolet radiation on *Escherichia coli* infected by phages, Luria and Latarjet have reached the conclusion

that when several particles of one phage strain infect the same bacterial cell they all can grow, and that the time of phage liberation and the yield of phage per bacterium are very little affected by the initial multiplicity of infection.

Luria and Palmer have made cytological studies of bacteria and of bacteriophage growth. Modifications in the Giemsa technique were worked out for obtaining clear and reproducible staining of the nuclear body in the *Escherichia* cell. The studies of the growth of phage indicate an intimate relation between this process and the behavior of the Feulgen-positive nucleoprotein bodies of the bacterial cell.

On completion of his research at the Ballistic Research Laboratory in Aberdeen, Maryland, which he carried on while on leave of absence from this Department, Dr. Ugo Fano resigned as a member of the Department to become a Research Associate of the Institution. From December 10, 1945 to June 22, 1946 he was in residence in New York City, and from then until September 7 at Cold Spring Harbor. During this period he carried on theoretical research work on nuclear physics at the Pupin Physical Laboratory of Columbia University, and on genetics at this Department.

Work on the special project dealing with the genetic aspects of the origin of bacterial resistance was continued during the past year. Until the end of 1945 this project was supported by funds appropriated by the Committee on Medical Research of the Office of Scientific Research and Development, and thereafter by funds appropriated by the Institution. Dr. S. E. Luria, on leave of absence from Indiana University, supervised the research work of the group, which consisted of Dr. E. F. Oakberg, Mrs. Elizabeth J. Oakberg, Mrs. Jean L. Palmer, Miss Rachel Arbogast, and Mrs. Evelyn M. Witkin, who, as a graduate student of Columbia University, held a research fellowship of the University.

Dr. Raymond Latarjet, Chef de Laboratoire, Institut Pasteur, Paris, who was in this country on mission for the Service des Relations Culturelles, Ministère des Affaires Etrangères, worked at this Department on the effects of radiations on bacteria and bacteriophages. Dr. G. Gasić, of the University of Chile, Santiago, Chile, continued research on leukemia as a guest scientist in MacDowell's laboratory. During the previous year he had held a Guggenheim Fellowship. Dr. Richard Miller returned from service in the Army in November 1945, and worked with MacDowell as an associate cytologist until August 1946, when he took a position with the Department of Anatomy, School of Medicine, University of Minnesota.

After an interruption of three years during the war, the Biological Laboratory resumed the Cold Spring Harbor Symposia on Quantitative Biology in the summer of 1946. A symposium was held from July 2 to 12, on the topic "Heredity and variation in microorganisms." The meeting brought about 120 scientists to Cold Spring Harbor—nine of them from Europe. Four members of the Department (Demerec, Latarjet, Luria, and MacDowell) presented papers on the program.

THE GENE

M. Demerec, R. Latarjet, S. E. Luria, E. F. Oakberg, and E. M. Witkin

Mutations in Escherichia Induced by Radiations

It was reported last year that mutations in *Escherichia coli* may be induced by ultraviolet radiation (2537 A), and that some of these mutations express themselves before the bacteria pass through the first division (zero-point mutations), whereas others show up during subsequent divisions. All detectable induced mutations have been expressed after about 13 bacterial generations (end-point mutations). During the past year M. Demerec and R. Latarjet, with the assistance of Miss Marion Crippen and Miss Nancy McCormick, studied the relation between various doses of ultraviolet rays and X-rays and the frequency of induced mutations.

In this work, Mrs. Witkin's B/r strain (resistant to radiations) and the regular B strain were used, and mutational changes from sensitivity to resistance to bacteriophage T1 were studied.

The data obtained in experiments with ultraviolet radiation show that the rate of zero-point mutations increases tremendously with the dosage, rising from 20 per 10^8 for a dose of 1000 ergs $\times$ mm.$^{-2}$ to a maximum of 70,000 per 10^8 for a dose four times as great. At this point a plateau is reached, followed by what seems to be a slow drop. The ascending part of the curve appears complex, rising more and more rapidly with the increases in dosage. It is fairly well represented by the formula $\log \log \mu = k D$, meaning that the log log of the mutation rate is proportional to the dosage. If one wanted to recognize in this curve the beginning of a multiple-hit curve, then the number of hits assumed would be approximately 10.

The first part of the end-point curve is similar to that of the zero-point curve; the ratio between end-point and zero-point mutants, in that region of the curves, is about 400:1. Later, the increase in the end-point rate lags behind the increase in the zero-point rate, and the two curves approach each other. The end-point curve does not show any drop, and continues upward until a mutation rate of 2.8 per cent is reached, which was the highest obtained. The very high dosage used at that point leaves only 2.2×10^{-6} per cent survivors.

It has been found that the relation between zero-point mutants and dosage follows a straight line, which can be considered the beginning of an exponential one-hit curve. This result agrees with most of the similar studies on dosage-mutation relations made by others, and suggests that mutation is induced by direct action of the radiation on a limited locus of the cell. The rate of end-point mutants increased a little more rapidly than the zero-point rate.

Similar results were obtained with resting and with growing bacteria, and with B/r and B strains, which differ in their resistance to radiations.

The results show no evidence of any relation between the ability of a radiation to produce sterilization and its ability to produce mutations. When similar amounts of energy are absorbed by the cell, either from ultraviolet or from X-radiation, similar rates of mutation are observed, whereas the sterilization rate is considerably higher with X-rays than with ultraviolet.

The evidence available at present does not permit a definite judgment regarding the mechanism of immediate and delayed mutations induced by radiations. All we are justified in saying is that the probable

site of change is inside the bacterium; that the change is complex, requiring, as a primary step, the absorption of radiant energy by several molecules; and that the volume within which the change occurs is not larger than might be affected by a single cluster of ionizations. This change is transmitted to the progeny; hence it behaves as a mutation. Since there is no valid reason to assume that bacteria do not have genes and chromosomes, the most probable explanation of the mechanism of the observed behavior is that it is a gene mutation, although this does not exclude the possibility that in addition to the gene some other material may be affected. The complexity of the change, suggested by the results obtained with ultraviolet radiation, could be explained by assuming that the gene is represented several times, a condition that would exist if the chromosome consisted of a number of chromonemata.

Irradiation of Bacteriophage during Intracellular Growth

The problem of bacteriophage multiplication inside the host cell, and, in general, of virus multiplication, remains as yet unsolved. What is the mechanism of production of the new phage particles, numbering up to several hundred, which a bacterium can liberate after having been infected by one or a few particles? Clarification of this problem may be of fundamental importance, not only in relation to viruses, but also in connection with the problem of gene duplication.

Luria and Latarjet tried to throw some light on this problem by exposing phage to ultraviolet radiation during the period of intracellular growth. Cells of *Escherichia coli,* strain B, were infected with phage T2 (or T7), then irradiated with ultraviolet light (80 per cent wave length 2537 A) during the interval of 21 minutes between infection and liberation of new phage. Several doses of radiation were given at different times during this interval. The number of bacteria that could still liberate phage after irradiation was determined by plating with sensitive bacteria, on which a plaque was formed for each bacterium that liberated any phage.

Immediately after infection with one phage particle per bacterium (single infection), the ability of bacteria to liberate phage is suppressed by radiation at an exponential rate closely similar to the rate of inactivation of free phage and much lower than the rate of sterilization of the bacterial cells. This indicates a direct action of the radiation on the intracellular phage. As time goes on, the "survival curve" for the infected bacteria shows progressively increasing resistance to the action of ultraviolet radiation. This resistance appears to be caused, during the first few minutes after infection, by increased resistance of the individual phage particles. This resistance reaches a maximum after about 12 minutes; then a decrease in resistance to high doses of radiation occurs, while resistance to low doses remains high. Later (15–18 minutes after infection) the curves appear to be of a "multiple-hit" type, as though suppression of the ability to liberate phage depended on inactivation of large numbers of independent units.

These results were interpreted as evidence of two processes taking place during phage growth: first, an increase in resistance of the intracellular phage, probably due to screening by an ultraviolet-absorbing material (nucleic acid?) accumulating around the phage; second, multiplication of the phage, with production of large numbers of particles, while resistance of the individual particles diminishes, probably because of utilization of the screening material.

The rate of increase in resistance—that is, of accumulation of the screening material—depends in part on the action on bacteria of some other substance present in phage lysates besides the active phage itself. This is shown by differences in resistance that depend, not on the number of phage particles adsorbed per bacterium, but on the amount of phage lysate with which the bacteria have been in contact. No information is yet available on the nature of this component of the lysates.

If bacteria are infected at the start with more than one phage particle (multiple infection), the survival curve for phage-liberating ability of the infected bacteria is of a multiple-hit type from the very beginning. Theoretical survival curves were calculated on the assumption that, if a bacterium contains n phage particles, its inactivation requires inactivation of all these particles. One obtains thus a family of survival curves of the form

$$y = 1 - (1 - e^{-x})^n.$$

Comparison with the experimental curves shows that the values of n calculated from the survival curves correspond fairly well to the average number of phage particles adsorbed per bacterium. This is interpreted as proving that when several particles of one phage strain infect the same bacterial cell, they all can grow (no "mutual exclusion"). In later phases of intracellular growth (after 15–18 minutes) the survival curves for multiple-infected bacteria become very similar to those for single-infected bacteria. This agrees with the known fact that time of phage liberation and yield of phage per bacterium are very little affected by the initial multiplicity of infection.

The data also provide evidence of the occurrence of wide fluctuations from one cell to another in the rate of each of the processes connected with phage growth. These fluctuations make it impossible to estimate the average number of intracellular phage particles at various times during growth from the data of ultraviolet inactivation. It is likely that the fluctuations in the rate of phage growth are responsible for the wide variability of the phage yields from individual infected bacteria (Delbrück).

Spontaneous Resistance to Bacteriophage

The study of the mutational pattern of phage resistance in *Escherichia coli,* strain B, was continued by Luria in two directions: first, a study of complex mutational patterns; and, second, a study of associated effects of mutations to phage resistance.

Resistance to some of the phages T1–T7 had previously been found (Demerec and Fano) to be produced in *E. coli* B by a number of independent mutations; some of these produce resistance to one phage only, some to two or three. Cross-resistance groups of phages can thus be established. If we indicate resistance to phage Tn by /n, the mutations most commonly found are the following: /1; /1,5; /6; /3,4,7. Strains resistant to more phages can result from successive mutations: /1,5/6; /3,4,7/1,5. Demerec and Fano occasionally found some rare one-step bacterial mutants resistant to phages not belonging to the usual cross-resistance groups. A study of these complex mutant types was undertaken by Luria, in an attempt to classify their origin. One could imagine that a complex resistance pattern might be brought about either by mutation at a different genetic site from those responsible for the simple mutations, or by simultaneous occurrence of several mutations.

Complex mutants were isolated by plat-

ing wild-type bacteria with suitable mixtures of phages. Complex mutant phenotypes were found occurring with lower frequencies than the simple mutants. These frequencies, however, were much too high to be explained by chance coincidence of two mutations in the same mutant clone. For instance, the mutation B/1,5 occurs at a rate 10^{-8} per cell per generation, B/3,4,7 at about 10^{-7}; the complex mutation B/1,5,3,4,7 occurs at a rate of the order of 10^{-10}.

Characterization of some complex mutants by large numbers of characters (sensitivity to phages T1–T7 and to several of their mutants, growth characteristics in complete media, and specific growth-factor requirements) proved that some complex mutants (B/1,3,4,7; B/1,5,3,4,7) are indistinguishable from double mutants (B/3,4,7/1; B/3,4,7/1,5). Each of the two complex mutants mentioned above proved to be, phenotypically, the exact superposition of two common mutant phenotypes. Other complex mutants could not easily be interpreted as combinations of simple phenotypes, mainly because they showed resistance to phage T2, stable resistance to which cannot be obtained in simple resistant types from our wild-type strain B. E. H. Anderson has suggested that coupled resistance to different phages results from mutations blocking some common step in the synthesis of substances needed for sensitivity to each phage type. The occurrence of complex mutants could be explained by assuming different blocks at various levels in the chains of reactions responsible for sensitivity. One must, however, assume an extremely complicated network of reactions, each shared by two or more of the chains of reactions leading to sensitivity to different phages. Additional complications are required to account for minor differences in sensitivity to some phage mutants. These considerations have been detailed in a paper presented at the Cold Spring Harbor Symposium on Quantitative Biology.

It seems likely that some genetic mechanism exists by which different mutations may be to some extent interdependent. This view is supported by a recent finding that the frequency of mutations to /2, apparently negligible for the wild-type B, is high in a special group of strains B/3,4,7. The frequent appearance of the B/3,4,7/2 mutant is not caused by any competitive advantage over B/3,4,7; no selection takes place in mixed cultures containing various proportions of the two strains.

Several mechanisms can account for the dependence of the mutation /2 on a previous mutation /3,4,7: (*a*) allelic changes at the same genetic site; (*b*) increased mutability at a different site; (*c*) suppression of a supposedly swift reversion of the mutation /2 to wild-type; (*d*) phenotypic expression of a /2 mutation that is masked when occurring in the wild-type because the wild-type allele of /3,4,7 provides an alternative bypath which compensates for the effect of /2. The mutation /3,4,7 would then cause elimination of a suppressor effect of its wild-type allele.

Mechanism (*d*) could account for some cases of complex resistant phenotypes: the phenotypic changes produced by very frequent suppressed mutations would generally be detected in association with the phenotypic changes produced by mutation at the suppressor locus. It does not explain cases, such as those discussed above, of apparent simultaneous occurrence of two stable mutations which occur also independently at low rates.

Further evidence for complex effects of mutations to phage resistance was provided by the observation that one of the mutations /3,4,7 (different from the one discussed above) also produces changes in sensitivity to phages T2 and T6. The

mutant bacteria adsorb these phages, but only 5–20 per cent of the cells liberate phage. This indicates a tie-up between genetically determined abilities to adsorb certain phages and to grow certain others. More observations of this type have been made and require further study.

A large number of phage-resistant mutants were studied for their growth rates in nutrient broth, both in order to detect metabolic alterations produced by the mutations and to collect data for an analysis of bacterial populations under various mutation pressures. Specific alterations of the growth characteristics were found associated with given mutations. These alterations may affect either the actual growth rate, the maximum titer, or the death rate of the bacteria. None of the mutants grows better than the wild-type; many of them grow worse. In mixed cultures different mutants generally grow without interactions, at rates predictable from their growth in pure cultures; however, some cases of interaction, probably due to diffusible products of metabolism, have been encountered.

Phage resistance patterns in dysentery bacilli. Many attempts have recently been reported to obtain nontoxic antigens from dysentery bacilli for use as vaccines. It was thought possible that mutations producing phage resistance might also produce a dissociation of the antigenic from the toxic properties of the type-specific antigens. Strains of *Shigella paradysenteriae* (Flexner) obtained from Dr. W. F. Goebel, of the Rockefeller Institute, were tested for sensitivity to phages T1–T7; a number of phage-resistant mutants were isolated. These were tested for antigenicity and toxicity in Dr. Goebel's laboratory. Although some variation in toxicity was found, none of the mutant strains was appreciably less toxic than the parent ones.

Some interesting observations were, however, made in the course of these tests. First, a close but not absolute correlation was found between antigenic-type and phage-sensitivity patterns, as already described by Burnet. Second, it was found that cross-resistance groups of phages determined from tests with dysentery organisms are different from those determined for *E. coli* B. This fact confirms the conclusion that cross-resistance is not a criterion of relatedness between phages. It seems also to support the idea that cross-resistance depends on suppression by mutation of some reaction necessary for more than one chain of reactions in the bacterial cells; these chains may be differently coupled in different organisms.

Resistance to Radiations in Escherichia

Further work was conducted by Witkin on the ultraviolet-resistant mutant of strain B of *Escherichia coli* (see Year Book No. 43). This variant, known as strain B/r, is characterized by stable and heritable resistance to ultraviolet radiation, and can be isolated by culturing survivors of irradiated samples of the parent strain.

It was found that the ultraviolet-resistant mutants exhibit marked resistance to X-rays as well. The survival of strain B as a function of both ultraviolet and X-ray dose, and the survival of the resistant strain as a function of X-ray dose, yielded logarithmic "one-hit" curves. The survival of the resistant strain plotted against ultraviolet dose, however, gave a nonlogarithmic "multiple-hit" curve.

A study of the mode of origin of the mutation was conducted, to determine whether the mutants arise spontaneously, or through induction by the radiation, or both. A necessary prerequisite to this investigation was the development of a method whereby the numbers of resistant bacteria presumably present in normal cul-

tures, if spontaneous mutation is involved, could be determined accurately. Since the resistance is relative, there was no immediately apparent selective procedure which would kill all sensitive bacteria without killing some resistant bacteria at the same time. A technique was worked out to overcome this difficulty, and proved highly reliable. The treatment involves a preliminary irradiation of the sample with a low dose of ultraviolet, followed by several hours of incubation. This treatment causes a delay in the division of sensitive cells, resulting in the production of long filaments. The resistant bacteria divide with no delay, forming large microcolonies. The sample is then given a second irradiation, which eliminates all the sensitive bacteria but leaves a few survivors in each resistant microcolony, so that a visible colony will develop for each resistant bacterium originally present.

Using this double-irradiation technique, experiments were conducted to test the hypotheses of spontaneous and induced mutation. The method used was that developed and fully described by Luria and Delbrück. The results were found to be completely consistent with the hypothesis that radiation resistance arises as a spontaneous mutation, with the radiation acting as a passive selective agent. The mutation rate, calculated on the basis of these experiments, was found to be about 1×10^{-5} mutations per bacterium per generation.

Concentrated centrifuged suspensions of bacteria of the parent strain, irradiated with very high doses of ultraviolet by Demerec and Latarjet, were found to contain about 5 per cent radiation-resistant mutants among the survivors, as compared with the spontaneous frequency of about 0.001 per cent. These figures are corrected for the differential survival of resistant bacteria. The mutation rate can thus be considerably increased by high doses of radiation.

The resistant strain B/r was found to be relatively resistant to penicillin and sodium sulfathiazole as well as to radiation. Fifty unrelated radiation-resistant strains were tested with penicillin and sulfathiazole, and were found to fall into four classes: some were resistant to both penicillin and sulfathiazole, some were resistant to neither, and some were resistant to one or the other. It was shown that resistance to penicillin and resistance to sulfathiazole are not due to coincidence of independent mutations. At least four different mutations must therefore be capable of producing the same resistance to ultraviolet and X-rays, with or without associated resistance to penicillin, to sulfathiazole, or to both. It seems likely that the antibacterial action of penicillin, sulfathiazole, ultraviolet rays, and X-rays may converge in the blocking of one common essential process, which is altered in those mutants that exhibit resistance to all four agents.

Preliminary studies of population dynamics in artificially prepared mixtures of strains B and B/r were conducted. When mixtures were subcultured in fresh medium daily, the proportion of normal to mutant bacteria showed no change over a period of 4 weeks. If the initial mixtures were incubated without subculture for this period, the proportion of mutants fell rapidly, and reached the spontaneous proportion within 3 weeks. The mutants thus exhibit a selective disadvantage, which operates under the conditions of aging cultures.

During the course of these experiments, an observation was made which may be of significance for many types of biological work with radiations. It was found that considerable differences in the sensitivity of bacteria to ultraviolet, and in their morphological development after irradia-

tion, are obtained depending on the type of medium used during the irradiation. The differences do not seem to be related to specific components of the medium, but are entirely dependent on whether it is a solid or a liquid. These differences cannot be explained by small variations in the amount of reflected radiation.

Mutation of Staphylococcus to Sulfonamide Resistance

It is generally known that bacteria can become resistant to growth-inhibiting agents. The mechanism by which this resistance is acquired, however, has often been debated. Mutation and selection have been shown to be responsible for resistance of bacterial strains to bacteriophages (Luria and Delbrück), to penicillin (Demerec), and to ultraviolet radiation (Witkin). Confusion exists concerning the origin of sulfonamide-resistant bacteria. It was important to clarify this phenomenon, first of all, in respect to clinical use of sulfonamides, since proof of the genetic origin of resistance would direct therapeutic practice by indicating how to diminish the danger of establishment of resistant variants. In the second place, the information already available on the mode of origin of resistance to sulfonamides might be utilized to gain information about physiological changes associated with mutations to resistance. Oakberg and Luria studied this problem, using sodium sulfathiazole (NaST) and a strain of *Staphylococcus aureus* designated as NRRL-313. A semisynthetic casein hydrolysate medium was found to support good growth while being relatively free of sulfonamide antagonists.

Attempts were first made to isolate resistant strains of bacteria directly, by plating a large number of cells on NaST agar and then isolating the colonies that developed. This technique proved unsuitable because of the presence of "inoculum size effect." If more than 10^7 cells were used, growth was complete even in saturated solutions of NaST. With smaller inocula, whose growth could be inhibited, the probability of detecting resistant cells was too low. More successful was a method utilizing a quantitative modification of the usual technique of serial transfers in liquid cultures containing NaST. At each transfer a range of inocula from 10^2 to 10^6 cells per milliliter of culture was tested with a range of NaST concentrations from 1×10^{-5} to 1×10^{-2} M. The inocula for each transfer were taken from the culture containing the highest concentration of NaST in which growth from 10^5 cells had occurred in the previous transfer.

Of three series of transfers, one yielded a strain with a 10-fold increase in NaST resistance, the other two gave strains with 1000-fold increases in resistance. Resistance was measured as the concentration allowing full growth with an inoculum of 10^4 cells per milliliter of culture. The most important feature was that increases in resistance appeared in the course of the serial transfers as sharp, discontinuous steps of different magnitude in different cultures. These abrupt variations appeared at random intervals during the serial transfers. Such stepwise increases in resistance are best explained by the hypothesis that resistant cells arise by infrequent mutations. Once a resistant mutant has appeared, it will grow selectively in the presence of NaST concentrations that inhibit the parent type.

In order to confirm this hypothesis and to obtain quantitative data on the frequency of the mutations, a technique of double exposure of bacteria to the drug was used. Much of the inoculum-size effect is due to the production of antagonists during the early uninhibited phase of bacterial growth in the presence of NaST.

Use of cells previously "inhibited," therefore, should avoid inoculum-size effect. It was found that if sufficient NaST was added to a broth culture to reduce the final titer from about 1×10^9 to 2 or 3×10^8 cells per milliliter, large numbers of these bacteria could be inhibited by moderate doses of sulfonamides. These bacteria could then be plated; and the scattered colonies that developed from NaST plates prepared in this manner, when isolated and tested, proved to be more resistant than the parent strain. Variant colonies isolated from the sensitive parent strain showed at least three different levels of resistance. From these resistant strains one could isolate by the same technique variants with higher resistance, again falling into three different levels. In turn, strains that had already undergone two mutations to resistance gave at least three classes of more resistant mutants. It is impossible to identify a given mutation by the increase in NaST tolerance it produces, since the same increase may be produced by several different mutations, and since the same mutation may produce different increases when occurring in different genotypes. The fact, however, that a strain that already has mutated twice can give three classes of mutants indicates that at least five different genetic changes producing resistance can occur.

The distribution of mutants in series of independent cultures started from small inocula of the parent strain was studied. The contents of each culture were plated in three test plates. The analysis of variance permitted comparison of the variation between plates from the same culture with the variation between plates from different cultures. Most of the variation in number of resistant colonies could be ascribed to differences between cultures. This is what would be expected according to the hypothesis of the mutational origin of the variants (Luria and Delbrück).

From the percentage of cultures failing to show resistant colonies, total mutation rates of about 10^{-9} per bacterium per generation were estimated. This rate represents the sum of the mutation rates for all mutations occurring at a certain level, not the rate of one individual mutation. The order of magnitude of the mutation rates at different levels was similar.

Ever since Woods and Fildes suggested that sulfonamides act by competing with essential metabolites in the bacterial cell, especially *p*-aminobenzoic acid (PAB), it has been thought that increased resistance to sulfonamides could be the result of heightened PAB synthesis. Tests of culture filtrates for ability to replace PAB as a growth factor in *Acetobacter suboxydans* and in a *p*-aminobenzoicless strain of *Neurospora crassa* showed that some of our mutant strains of *S. aureus* produced more of a substance having PAB activity than did the sensitive parent strain; others did not. When resistant strains, having undergone several successive mutations, showed increased PAB production, this was not of sufficient magnitude to explain the level of NaST tolerance of these strains. These results were explained by the finding that only one mutation resulted in greater synthesis of PAB. Once this mutation had occurred, further increases in NaST resistance did not involve greater PAB production. On the other hand, this mutation can occur in strains having already undergone other mutations to resistance. Thus, at least four mutations to sulfonamide resistance have no effect on extracellular production of PAB.

This situation can best be explained by assuming that genetically determined changes in a number of different metabolic processes of the cell result in increased

resistance to sulfa drugs. This in turn indicates that sulfonamide action is exerted on a number of metabolic processes.

Penicillin Resistance in Bacteria

Demerec has previously established that the ability of *Staphylococcus* to grow in progressively increased amounts of penicillin is acquired *in vitro* by successive mutations, each contributing further resistance. The resistant bacteria grow in the presence of penicillin without destroying it. It has been reported repeatedly, however, that the great majority of the penicillin-resistant strains isolated after penicillin therapy produce a penicillin inactivator, possibly analogous to the penicillinase produced by other bacteria. Production of penicillinase has thus been considered the cause of resistance and of therapeutic failures. Luria and Arbogast undertook a comparison of the penicillinase-producing staphylococci with penicillin-resistant strains *in vitro*. It was found that penicillinase-positive strains may consist of cells sensitive to penicillin, as shown by the inability of small inocula to grow in its presence. Large inocula of these cells succeed in growing because they destroy enough penicillin to reduce its effective concentration below the bacteriostatic threshold. Selection of resistant mutants can still be obtained in the presence of penicillin when the concentration is reduced by penicillinase to a level that permits growth of the mutants. These mutants produce as much penicillinase as the parent strain.

Since penicillinase-positive strains are supposed to arise *in vivo* from negative strains under penicillin therapy, an attempt was made to reproduce this change *in vitro*. Sensitive or resistant bacteria from negative strains were grown for long periods in the presence of penicillin under a variety of conditions, but no penicillinase production was detected. The strains used included some, obtained through the courtesy of Dr. W. W. Spink, that were supposed to have given penicillinase-positive variants *in vivo*.

Because of these failures, it was suspected that penicillinase-positive strains may be selected *in vivo* from among a mixture of strains. Resistant mutants from penicillinase-positive strains are more likely to be selected in the course of therapy, because of the lower effective concentration of penicillin around them. If a mixture of positive and negative strains is present, the positive one will have a greater chance of surviving penicillin treatment. Mixed infections of this type may be frequent if penicillinase-positive strains are of rather common occurrence, and are likely to be difficult to recognize by routine laboratory tests. No experiments have been recorded on the appearance of positive from negative strains during penicillin treatment of experimental infections with pure cultures in animals.

Luria and Arbogast then tested 47 strains of *Staphylococcus* isolated from patients before penicillin treatment, which were kindly supplied by Miss B. Johnson. The results of these tests supported the suggestion made above. Among these 47 untreated strains, 11 were penicillinase-positive. Of these, 3 had fairly sensitive cells, and 8 were more resistant, possibly owing to previous contacts with penicillin. Of the 36 penicillinase-negative strains, 1 was quite resistant, 1 had medium resistance, and the others were more or less sensitive.

Several pairs of these strains had been isolated from the same patient, and in some cases a pair consisted of one penicillinase-positive and one penicillinase-negative strain. It is clear that penicillinase-positive strains are frequent enough in untreated patients to cast doubt on their

origin as variants from negative strains in the course of penicillin therapy.

Penicillinase production may affect the results of penicillin therapy both by destroying penicillin and by favoring the establishment of resistant substrains because of greater opportunity for selection of the latter. It is clear, however, that the presence of penicillinase-producing strains does not immediately exclude the usefulness of penicillin therapy. Positive strains consisting of sensitive cells may prove susceptible to proper treatment.

A series of experiments on penicillin resistance in hemolytic streptococci indicated that resistance in this case also is built up in successive mutational steps. The increase in tolerance, however, is so small (from 0.01 to 0.025 units per milliliter in three steps) that these mutations are likely to be of no clinical significance.

Streptomycin Resistance in Bacteria

Genetic study of the mode of origin of resistance to penicillin in *Staphylococcus* (Year Book No. 43, pp. 109–110) indicated that a process comparable to mutation is responsible for the resistance. It revealed also that the resistance develops in steps, and that the progress of the building up of resistance is more rapid with each step. The first step in the development of resistance is small, so that several steps are required to obtain a high degree of resistance.

During the past year similar experiments were conducted by M. Demerec, with the assistance of Miss Marion Crippen and Miss Nancy McCormick, using streptomycin as antibiotic agent and *Escherichia coli*, strain B, and *Staphylococcus aureus*, strain NRRL-313, as test organisms. Streptomycin was obtained from Merck and Company, Inc. and from Chas. Pfizer and Company, Inc.

Experiments were conducted to test the reaction of bacteria to streptomycin by plating them on agar plates containing various concentrations of the antibiotic. It was found that neither *Staphylococcus* nor *coli* is affected until a threshold concentration of about one unit per milliliter has been reached. Increase in concentration after that point rapidly decreases the number of surviving bacteria that can form colonies. For example, at a concentration of 2 units per milliliter only about 2×10^{-8} *coli* and about 1×10^{-4} *Staphylococcus* survive. Values for survivors at a concentration of 4 units are 1×10^{-6} for *coli* and 1×10^{-5} for *Staphylococcus;* at 8 units, values are 4×10^{-8} for *coli* and 1×10^{-7} for *Staphylococcus*. The slope of the survival curves is very steep for concentrations slightly higher than the threshold, but the slope decreases as values for concentrations become greater. Curves showing numbers of surviving *Staphylococcus* and *Escherichia* after plating on nutrient agar containing various concentrations of streptomycin are very similar to the curve obtained in experiments with *Staphylococcus* and penicillin.

Strains established from colonies grown on a medium containing a high concentration of streptomycin showed a higher degree of resistance than the original strain. This condition persisted after 10 and 20 transfers, indicating that the resistance is an inherited characteristic.

An experiment in which similar samples of bacteria taken from independent cultures and from a single culture were grown on a certain concentration of streptomycin, in order to determine the number of bacteria resistant to that concentration, showed a much greater variability between samples from independent cultures than between samples from a single culture. This is to be expected if

resistance originates through mutation, and independently of streptomycin treatment.

It was found that the resistance to streptomycin also develops in steps. A difference between streptomycin and penicillin in this respect was observed, however. Whereas the first resistance step in the case of penicillin is invariably small, the first resistance step in the case of streptomycin shows considerable variability and, in an appreciable proportion of cases, overlaps the higher steps. In other words, a high degree of resistance to streptomycin may be obtained either in one step, in two steps, or in several steps. From a clinical standpoint, this is an unfortunate property, since it greatly favors the origin of resistant strains. In clinical treatment with penicillin, the development of resistant bacterial strains can be avoided if the concentration of penicillin is kept high; but use of a high concentration of streptomycin can only lower the chances for development of resistant strains, not prevent their origin.

Experiments showed that strains of *Staphylococcus* that became resistant to streptomycin remained as sensitive to penicillin and to sodium sulfathiazole as the original strain from which they were derived.

Cytological Studies of Bacteria and of Bacteriophage Growth

Nuclei in bacteria have been repeatedly described, although agreement concerning their structure, development, and function has by no means been reached. In recent years, Robinow and other workers have developed techniques that seem to give reproducible results with a number of bacteria, and have described the appearance of "nuclear bodies" stainable by Giemsa or Feulgen technique in a number of bacterial types, including *Escherichia coli*. These Feulgen-positive bodies must contain large amounts of desoxyribose nucleic acid; they are possibly involved in the transmission of hereditary characters and in reproduction of bacteriophages, since the latter consist mostly of nucleoprotein of the desoxyribose type.

Mrs. J. L. Palmer made a systematic study of various techniques for obtaining clear, reproducible stains of the Robinow bodies in *E. coli*, using both Giemsa and Feulgen stain. The techniques adopted as best are described below.

Giemsa stain. A drop of cell suspension from solid or liquid medium is deposited on a slide cleaned in chromic solution, stored in alcohol, and flamed before use. The drop is fixed *before drying* by inverting for 2 minutes over a depression slide containing 2 per cent OsO_4 solution. The slide is then allowed to dry in air, is immersed in 1 N HCl at 60° C. for 10 minutes, rinsed in distilled water, and allowed to stay 5 minutes or more in phosphate buffer at pH 6.9. Staining is done in a 1:80 water dilution of a stock solution of 1 g. dye in 30 cc. glycerin + 30 cc. CH_3OH. The best results are obtained by staining 5 minutes, washing in water, and drying without any differentiation. The stained preparations often do not keep very well, but occasionally they remain good for months.

Feulgen stain. This gave less satisfactory results than the Giemsa stain. The technique adopted was the following: (1) fixation and HCl treatment at 60° C., as above; (2) rinsing in 1 N HCl at room temperature, then in distilled water; (3) treatment in sulfurous acid–fuchsin solution for 4 hours; (4) washing in running tap water for 30 minutes, then rinsing in distilled water and drying. The sulfurous acid–fuchsin solution was prepared according to Coleman and de Tomasi.

Feulgen technique was used mainly to check the results obtained with Giemsa;

the study of fine details is more feasible with the latter stain because of greater contrast.

Staining of Escherichia coli. Mrs. Palmer studied the results of staining *E. coli* B in various phases of growth. Slides were examined with an oil-immersion objective. Cells from fully grown slants or 24-hour aerated liquid cultures are small, and stain uniformly dark with Giemsa or Feulgen. If they are transferred to fresh medium, differentiations appear within 10 minutes. By 20 minutes, practically all cells show the aspect typical of a growing culture: dark-stained "nuclear" bodies in an unstained cytoplasmic background. Throughout the logarithmic phase of growth, cells of various lengths contain two, four, or more bodies, according to their length. A few very small cells have only one nuclear body. The shape of these bodies varies from round to elongated, rod-, or dumbbell-shaped; the various shapes appear to be phases of a process of elongation followed by division. The direction of elongation seems to be at different angles with the cell axis; but owing to the smallness of the cells the process of division cannot easily be characterized in its fine details.

Some trials with *Bacillus subtilis* showed that these larger bacteria are much better material for the study of the nuclear bodies. Study of *E. coli* was important, however, in relation to the *coli* bacteriophage work. Luria and Palmer studied the modifications in the cytological picture occurring during intracellular phage growth.

Phage T2. Growing bacteria were mixed with various amounts of phage T2 in broth (latent period before lysis 21 minutes), and samples were taken and fixed at intervals, then stained. To facilitate interpretation of results, each slide also received at a different point a drop of a control culture without phage; this insured that the observed modifications were not due to unsuccessful staining. When the initial ratio of phage to bacteria is 5:20, practically all bacteria are infected very early. After 2–3 minutes, most bacteria appear normal in the stained preparation; occasionally some nuclear bodies show slight deformations. After 4–5 minutes, many cells show moderate swelling and a disruption of nuclear bodies, most of which have variously altered shapes and show a tendency to migrate to the periphery of the cell. By 7–8 minutes this process is more advanced and involves more cells. By 10 minutes practically all cells are deeply affected. The nuclear bodies are replaced by irregular blocks of stainable material, which begin to fill more and more of the cell. As time goes on, the stainable material increases and fills up most of the cells, while becoming progressively less compact and more granular in appearance. By 20 minutes practically all cells stain heavily and uniformly, though in granular form. After 21 minutes, one sees bacteria undergoing lysis, mainly in the form of disrupted cell walls still faintly stained, with some darker granules. Large amounts of debris are visible in the field. An interesting appearance is presented by the unlysed cells still visible after 25–40 minutes: the outline of their surface is not smooth, but irregular, with bumps, as if stainable material had become attached here and there to their surface. It is known that with phage T2 there is a phase of "lysis inhibition," caused by adsorption, at a critical time near lysis, of an excess of phage liberated by other cells lysed in the vicinity. The lysis-inhibited cells may remain unlysed for hours (Doermann). The irregular outline of the cells remaining unlysed after 25 minutes is likely to be due to this massive readsorption of phage.

It appears from these observations that the first cytologically detectable reaction to

multiple infection by phage T2 is a disruption of nuclear bodies, whose material seems to migrate to the periphery of the cell, possibly surrounding the growing phage. This process may be responsible for the early increase in ultraviolet resistance of intracellular phage described by Luria and Latarjet in another section of this report. The subsequent gradual filling up of the cell by stainable material is likely to correspond to the actual growth of the phage. The amount of stainable material present at late stages of intracellular phage growth is much greater than the amount of material present at the start in the nuclear bodies. This seems to indicate a greatly increased synthesis of this material under the stimulus of phage growth. The above-described results, obtained mainly with the Giemsa stain, were confirmed with Feulgen. This seems fair evidence that the rate of formation of desoxyribose nucleic acid in the bacterial cell increases during phage growth.

Some attempts were made to find out whether in the case of single infection (one phage adsorbed per bacterium) the cytological modifications were different. It was found difficult, however, to work under these conditions. In order to obtain single infection, one must use amounts of phage sufficient to infect only part of the bacteria; the presence of many noninfected bacteria, and of some infected much later than others, complicates the picture. No clear difference was found in the cytological appearance of the infected cells.

A very different picture is shown, however, by bacteria very heavily infected with phage T2 (50–200 particles per bacterium). Delbrück has found that under these conditions lysis takes place without phage liberation, possibly through damage to the cell wall (lysis from without). When bacteria thus infected with T2 were stained, their cell walls immediately appeared faintly stained and granular instead of colorless. The nuclear bodies were visible and remained unchanged for several minutes, while the size of the cells increased much more than in the cases described above. By 10–15 minutes, disruption of many cells had occurred; empty cell walls in course of disintegration were common. Some not-yet-disrupted cells still showed intact nuclear bodies; others, already badly distorted, showed bodies that had become confluent, forming a central string of material. The disintegration proceeded rapidly, and after 20–30 minutes the microscopic field showed only remnants and debris of ruptured cells. It seems, then, that the attack of large numbers of T2-phage particles on a bacterium leads to rapid destruction of the cell wall, without specifically involving the nuclear bodies as in cases in which phage growth takes place.

The stainability of the cell wall after mass infection is evidence of the stainability of the phage particles, although these are too small to be individually resolved.

Phage T1. The cytological picture is much less impressive during growth of phage T1. Even when all cells are infected, a large number of them appear almost normal up to the time of lysis (beginning at 13 minutes). The main alteration, when present, is elongation and possibly merging together of nuclear bodies into thin, dense, rod-shaped forms. Some club-shaped bodies are formed. The cell size does not change; lysis is reached with little or no accumulation of stainable material in most cells.

Phage T7. Still different is the picture obtained after infection with phage T7. Here, after 5–7 minutes, some of the nuclear bodies in most infected cells become swollen, spindle-shaped, and wider than the cell itself, which bulges where these bodies are. These swollen bodies

remain very dense, and increase in size, while other nuclear bodies in the same cells become faint and small and often apparently disappear, leaving large sections of the cells without nuclear structures. One or two swollen bodies per cell remain. At the time of lysis (13–15 minutes after infection) many cells are seen disintegrating, with faint, torn cell walls and large amounts of debris.

All together, these preliminary attempts to observe phage growth by means of cytological staining reveal the existence of changes specific for each phage; some of these can already be correlated with known aspects of phage growth, and indicate an intimate relation between this process and the behavior of the Feulgen-positive nucleoprotein bodies of the bacterial cell. Further studies should be of interest, in relation both to phage growth and to the nature and function of the "nuclear bodies."

Aerosol Method for Chemical Treatment of Drosophila melanogaster

During the past year genetic tests were completed with the *Drosophila* material treated by the aerosol method described in last year's report (Year Book No. 44, pp. 119–121). Males were kept in atmospheres containing fine aerosols of aqueous solutions of various chemicals. Since the aerosol droplets were less than 1.5 microns in diameter, it was hoped that the chemicals used might enter the tracheae of flies, and, through the heavily tracheated gonads, might reach and affect the sperm without producing injurious effects on other organs. The tests with dyes reported last year indicated that, in an appreciable number of cases, intake was through the proboscis and the alimentary tract; however, the presence of stained regions in the testes suggested that the aerosols of at least some chemicals reached the germ cells.

In experiments conducted this year by M. Demerec, assisted by Mrs. J. S. Buchanan, males were exposed to aqueous aerosols of nineteen chemicals, including oxidizing, reducing, and wetting agents, and dyes. When exposure to an aerosol killed the flies, the concentration of the solution was adjusted so that between 10 and 15 per cent of survivors would be left after about 7 hours of treatment. In cases where the aerosolized chemical did not produce an injurious effect, the maximal feasible concentration was used and the time of treatment was extended to about 14, or in some cases about 21, hours. Treated males were mated with females carrying the ClB chromosome, and the first-generation Bar females were tested for lethals in the X chromosome which they had received through the treated sperm. Each male was kept with 2 or 3 females for 14 days after treatment, then transferred to another culture with new females. Results obtained in earlier experiments (Year Book No. 39, pp. 215–216) indicate that within a period of 14 days males exhaust the sperm that was mature on the first day, and that thereafter they make use of sperm that on the first day was in the spermatocyte stage. In our experiments, therefore, matings of the first set of females were made to test the effects of the treatment on mature sperm, and matings of the second set of females to test the effect on spermatocytes. All F_2 cultures that were suspected of carrying lethals were tested further, in order to ascertain whether or not lethals were present. Data obtained in these experiments are summarized in the accompanying table.

It is evident from this table that methyl-*bis*(betachloroethyl)amine is the only one of the listed chemicals that induced genetic changes at a rate high enough to be detected in our experiments. Methyl-*bis* (betachloroethyl)amine is a nitrogen mus-

X-CHROMOSOME LETHALS IN THE SPERM OF MALES TREATED WITH VARIOUS CHEMICALS

TREATMENT	MATINGS			
	1–14 DAYS		AFTER 14 DAYS	
	Sperms tested	Lethals	Sperms tested	Lethals
Control	4581	2	3174	1
Hydrazine hydrate	3645	2	3226	4
Mercuric chloride	2138	2	971	0
Silver nitrate	997	0	396	0
Potassium ferricyanide	997	1	244	0
Potassium permanganate	821	0	159	0
Copper sulfate	660	0	364	0
Phenol	1178	1	571	0
Sodium tetradecylsulfate	4126	0	2603	0
Sulfanilamide	752	0	439	0
Sodium sulfathiazole	789	0	584	0
Crystal violet	1973	1	869	0
Toluidine blue	591	1	625	0
Neutral red	601	1	545	0
Safranin O	618	0	652	0
Janus green	523	0	320	0
Methyl green	2397	1	2230	0
Fast green	1445	0	955	0
Acriflavin	2178	1	1219	0
Methyl-*bis*(betachloroethyl)amine	2059	58	450	8

tard related to sulfur mustard (mustard gas). Mustard gas has been found by C. Auerbach and J. M. Robson, of the University of Edinburgh, to be effective in producing genetic changes in *Drosophila*. In their experiments, exposure of males to a low concentration of the gas induced genetic changes in the sperm. Methyl-*bis* (betachloroethyl)amine is a salt, readily soluble in water. In our experiments a 2 per cent aqueous solution was aerosolized; thus the chemical was applied partly in solution, in the form of minute droplets, and partly as minute solid particles, since from some droplets the water must have been eliminated through evaporation. Aqueous solutions of methyl-*bis*(beta-chloroethyl)amine are known to be stable at pH's lower than 7. Since the solution used by us had a pH of 2.6, and since this pH was not detectably affected by aero-solization, it seems likely that the observed genetic effect was induced by methyl-*bis* (betachloroethyl)amine rather than by a gaseous product of its decomposition. It appears probable, therefore, that fine aero-sols may reach the testes of exposed males and that the aerosol technique may be used for studies of the effectiveness of various chemicals for inducing genetic changes in the sperm.

ORGANIZATION OF THE CHROMOSOME

BERWIND P. KAUFMANN, MARGARET R. MCDONALD, AND HELEN GAY

In an approach to the problem of the nature of the gene, we have continued our studies on the organization of the chromosome. Analysis has involved cytological observation of the structure of chromosomes at the various stages of mitosis in living and treated cells of a series of plants and animals. In the cycle of coiling and uncoiling attendant on their multiplication, the chromonemata reflect on a microscopically detectable level the adjustments requisite for duplication of the constituent genes and their distribution into daughter nuclei. Although the more general aspects of the mitotic process have long been known, many questions remain concerning the mechanism of splitting and coiling of the chromonemata, and the synthesis and distribution of materials within the chromosome. Much of the information now available on these and other controversial problems has been gained by indirect methods, and the cytological observations have been made primarily on fixed and stained cells. Supplementary studies on living cells have in general been less rewarding, because the relative transparency of the cell when viewed with the ordinary microscope obscures fundamental detail. Within recent months optical systems have become available that convert slight, invisible phase changes in the light passing through the specimen into intensity differences that can be seen. We have only recently initiated a series of experiments utilizing such a phase-contrast microscope, but the preliminary observations give promise of providing more adequate and critical information concerning the organization of the chromosome than was previously possible.

Another level of analysis has involved the use of various types of radiation in an effort to detect selective action on different chromosomal components. By determination of the distribution of X-ray-induced breaks along the chromosome, some insight has been gained into its linear organization with respect to the location of euchromatic and heterochromatic regions. In Year Book No. 44 a partial analysis was presented of the data accumulated in a study of a large number of induced rearrangements among the chromosomes of *Drosophila melanogaster*. Distribution of the breaks that participate in viable recombination was found to be nonrandom with respect to the number of discs per division or subdivision of the salivary-gland chromosome. The highest proportion of breaks in relation to salivary-gland-chromosome length occurred in the intercalary subdivisions designated on Bridges' map of the X chromosome as 12E, 11A, 12D, 1F, 7B, 9A, 16F, 4E, 4A, and 3C. These regions thereby simulate the behavior of the heterochromatic regions lying adjacent to the centromeres; and it was suggested that they also contain heterochromatin.

Additional evidence in support of this interpretation is supplied by observations of nonspecific pairing between such intercalary regions as 3C, 11A, 12D, 12E, and 19E, and also between them and the proximal heterochromatic regions of the various chromosomes. It seems reasonably certain, therefore, that these intercalary subdivisions contain heterochromatin; but it remains to be determined whether some of the other regions, which are not characterized by high break frequency, may not also contain heterochromatin. In order to obtain information bearing on this question, the data concerning the distribution of more than 1400 breaks in the X chromosome were subjected, in collaboration with

Dr. U. Fano, to a more rigid statistical analysis than was reported in Year Book No. 44. As a first approximation, an effort was made to determine whether the coefficients of breakage for the various divisions provide a normal frequency distribution. The coefficients were derived by comparing the number of recorded breaks with the number expected on the basis of random distribution according to the length represented in the salivary-gland chromosome. A histogram was prepared, as shown in figure 1, using the logarithms of

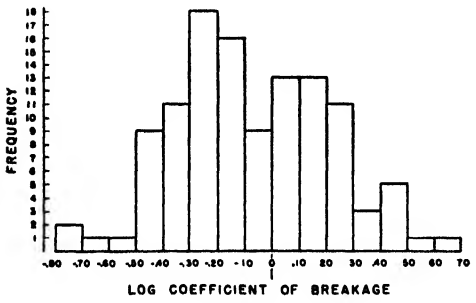

FIG. 1. Frequency distribution of coefficients of breakage of the 114 subdivisions of divisions 1 to 19 of the X chromosome of *Drosophila melanogaster*. Logarithms of coefficients used to symmetrize the data.

the coefficients to symmetrize the data, and counting each coefficient as a unit regardless of the number of breaks involved in its determination. It is apparent from a casual inspection of the graph that there is no striking bimodality, such as might be expected if a group of subdivisions differed markedly from the others. An additional test for bimodality was applied by using Fisher's test of departure from normality, which utilizes the moments of the third and fourth powers. These calculations provided the following values of g_1 and g_2:

$$g_1 = 0.31 \pm 0.23 \qquad g_2 = 0.51 \pm 0.45$$

Neither value is significant, so that the fluctuations may be regarded as those to be expected on a normal frequency distribution. Interpretation of these findings in the light of the knowledge that such subdivisions as 11A, 12D, 12E, and 19E contain heterochromatin leads to the conclusion that intercalary heterochromatin is distributed throughout the X chromosome, and not restricted to a few widely separated loci. Localization of the smaller or more "obscure" intercalary heterochromatic regions will require the use of various methods of analysis outlined in Year Book No. 43. Since modification of the capacity of a gene for expression may follow a shift in its position with respect to euchromatin and heterochromatin, the location of these materials is one of the essential steps in the study of the organization of the chromosome.

Ionizing radiations have been used also in an effort to define more precisely the processes involved in breakage, which disrupts the linear continuity of the chromosome, and in recombination, which restores such continuity. Since the potential breaks induced by treatment of the chromosomes of the spermatozoon of *Drosophila* do not participate in the formation of new combinations prior to the time of fertilization, this material affords an opportunity—as outlined in Year Book No. 44—for determining the effect of supplementary radiation on the processes of chromosome breakage and recombination. In experiments designed for this purpose it was found that near infrared radiation (in the wave-length range centering around 10,000 A) accelerates those processes that make available for transfer in copulation sperm which was not mature at the time of the X-ray treatment. A direct measure of the effect of supplementary radiation of long duration on the X-ray-induced potential breaks was therefore not obtainable. It was found, however, that near infrared radiation when used prior to X-rays effects a marked in-

crease in the frequency of viable chromosomal rearrangements as compared with the frequency in controls receiving only the X-rays.

There are other (nonviable) types of chromosomal rearrangement that lead to death in embryonic stages of the individuals carrying them. The production of the major part of such dominant lethals has been attributed to the union of sister chromatids at the position of the break so as to produce either a dicentric chromosome or an acentric fragment. Through the loss of the fragment, and breakage at anaphase of the bridge formed by the dicentric chromosome, nuclei arise carrying unbalanced and inviable combinations of genes and chromosomes. Pretreatment with near infrared radiation does not produce any marked increase in the frequency of this type of X-ray-induced change.

The "sensitizing" effect of near infrared radiation on the chromosomes of the spermatozoon of *Drosophila melanogaster* appears, therefore, to be greatest in the production of rearrangements involving two or more breaks, and slight or absent in the production of the single-break type of alteration. Because of this finding it seemed important to determine whether supplementary radiation has any effect on the frequency of lethal mutations induced by X-ray treatment of spermatozoa. Gene mutations in general have been attributed to some intramolecular reorganization that is not associated with a detectable chromosomal rearrangement, although a series of cytogenetic studies has indicated that some of the apparent genovariations are not dissociable from chromosomal aberrations, such as inversions, translocations, and small deficiencies. Some of the induced lethal mutations of *Drosophila* have been found in previous studies to be connected with such aberrations, although the majority have not revealed any chromosomal alterations identifiable by genetic tests or analysis of salivary-gland chromosomes. A series of experiments was accordingly initiated to measure the effect of near infrared radiation on the frequency of X-ray-induced sex-linked lethal mutations in the Swedish-b stock of *D. melanogaster*. By careful control of experimental conditions it was possible to avoid the complicating effects of posttreatment on the maturation of sperm, so that measurements were made of the effect of near infrared radiation when used after the X-ray treatment as well as before it.

An X-ray dose of 3000 roentgens was administered at the rate of 175 r per minute, using a Universal-type tube operating at about 80 kilovolts and 5 milliamperes. Males that had been (or were to be) treated with near infrared radiation were exposed to the X-rays simultaneously with controls that received no supplementary treatment. The source of the near infrared radiation was a commercial drying lamp, used in conjunction with a plano-convex condensing lens and two filters—one of Corning glass (no. 2404), and the other a saturated solution of iodine in carbon tetrachloride. The Swedish-b males were exposed in a vial surrounded by a cooling coil (which carried running tap water) for a period of about 48 hours.

At present the data have been only partially assembled, but the preliminary results reveal no marked or statistically significant differences between the percentages of lethal mutations induced in the flies receiving both the near infrared radiation and the X-rays and in those receiving only the X-rays. For example, pretreatment with near infrared provided, in a sample of about 800 sperms tested, 6.25 per cent of lethals, while in the controls there were 6.5 per cent in a sample of about 700. Similarly, in the posttreatment series, there were 5.6 per cent of lethals among the

group of about 600 sperms derived from males that had been exposed to near infrared radiation, and 6.2 per cent among a group of controls of about the same number. It appears, therefore, that near infrared radiation is no more effective in influencing the frequency of X-ray-induced recessive lethals than of dominant lethal changes. The presentation of a general interpretation, however, must await the accumulation of more complete data, including the cytogenetic analysis of a sample of the X chromosomes transmitting the induced lethals.

A further approach to the problem of submicroscopic organization of the chromosome has involved the use of biochemical and histochemical methods for the detection of specific cellular constituents. Work in various laboratories during past years has shown that the chromosomes probably contain nucleic acids and proteins. Nevertheless, our knowledge remains meager concerning their fundamental chemical composition and organization. We have accordingly organized a program designed to investigate some of the many questions that still remain unanswered. Are desoxyribose nucleic acids, in combination with the histones or more complex proteins such as chromosomin, the primary ingredients of the chromosomes? What role do these substances play in the processes of gene reproduction? Do the various desoxyribose and ribose nucleoproteins differ only in their protein components, or do they differ also in their nucleic acid constituents? What are the differences in chemical structure between euchromatin and heterochromatin? How do the proportions and types of chromosomal components change during the cycle of mitosis?

Answers to such questions may possibly be obtained by histochemical analysis of chromosomes—utilizing ultraviolet absorption spectra, or chemical reagents—or by studies of the physical and chemical properties of cellular extracts. Inasmuch as the latter procedures in themselves tell us little of the changes occurring as the various materials are synthesized and utilized during the different stages of mitosis, we have focused our attention on the application of histochemical methods. This has necessitated a critical study of the various procedures already in use and the development of new histochemical techniques for such cellular components as ribose and desoxyribose nucleic acids and the several types of protein. For example, a sensitive test for tryptophane applied to smears or sections of dividing cells should provide information concerning the locations and proportions of proteins of the histone and nonhistone types, since the former are deficient in this amino acid, whereas the latter are rich in it. Several years ago, Dr. R. W. Bates, working in these laboratories, developed an extremely rapid and sensitive modification of the May and Rose test for tryptophane. He found that in the presence of a suitable oxidizing agent, such as sodium nitrate, the blue compound formed by the union of *p*-dimethylaminobenzaldehyde with the indole ring in the presence of concentrated hydrochloric acid is developed in 5 minutes instead of the 48 hours previously required. We have attempted to modify this procedure so that it would serve as a reliable histochemical test. Preliminary experiments with plant and animal tissues have shown that the reaction is changed greatly by the type of fixative used in killing and hardening the tissue. Reagents containing either chromic acid or formalin—and many of the more valuable fixatives carry these ingredients as essential components—cannot be used because they prevent the development of the colored compound. Fortunately, however, it was found that nucleic acids do not inhibit this test for tryptophane, although they are

known to interfere with other tests for this amino acid. It has been necessary to alter the procedure recommended by Bates, to avoid the drastic action of the concentrated acid on cellular structures. Additional modifications will be required before the method may be regarded as a sensitive histochemical test, although at the present level of development it has been possible to detect differences in color intensity in nuclei and cytoplasm at different stages of mitosis.

A further line of attack in the solution of problems of the organization of cellular constituents involves the use of crystalline enzymes. In order to obtain decisive results with an enzyme it is essential to prove that (*a*) the enzyme is pure, (*b*) it is specific in its enzymatic action, (*c*) it has access to the substrate which it attacks, (*d*) the specific groups are in the proper condition to be acted upon by the enzyme, and (*e*) no endogenous enzymes are present that are capable of acting before or after the one added and thus confusing the results. The conclusions derived from many of the previous studies utilizing enzymes are open to criticism because of failure to control some or all of these variables. It has been necessary, therefore, to devote considerable time, before proceeding with our enzyme studies, to the preparation and careful assay of the enzymes with which we propose to start the investigation. Stocks of crystalline trypsin, chymotrypsin, ribonuclease, and pepsin have been prepared by methods developed in the laboratories of Dr. J. H. Northrop and his collaborators at the Rockefeller Institute for Medical Research while one of the writers was an active member of that group. Partially purified desoxyribonuclease has also been prepared, by the method of Dr. M. McCarty, and attempts (so far unsuccessful) have been made to crystallize or otherwise purify this enzyme. These crystalline enzymes are now being assayed not only for their own specific activity, but also, since crystallization alone is no criterion of purity, for other activities that might conceivably be present. It has, for example, been recently demonstrated that at least some preparations of crystalline ribonuclease can split not only yeast nucleic acid but also proteins. We have started an investigation to determine whether this proteolytic activity is due to an intrinsic property of the ribonuclease molecule or to an impurity. The latter possibility would at present appear to be the more likely, since the various samples of ribonuclease that we have prepared vary in their proteolytic activity. These are all long-range undertakings, which have required enlargement of our chemical laboratory and the installation of temperature-control equipment adequate for such experiments. Since the work is in its preliminary stages, informative results cannot be presented now, but should be available for the next annual report.

GENETIC STRUCTURE OF NATURAL POPULATIONS

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Darwin's theory of evolution by natural selection is accepted by most biologists despite the fact that it is based mainly on inference from indirect evidence and on analogies with artificial selection as practiced in domesticated animals and cultivated plants. Direct observation of and experimentation with natural selection are seldom possible. Evolutionary changes in nature are as a rule too slow to be perceptible within a human lifetime. Exceptions to this rule are rare, and when they

do occur the organisms concerned may not be favorable for genetic investigation. The opportunity offered by certain natural populations of the fly *Drosophila pseudoobscura* is, therefore, an exceptional one. Three types of third chromosome, referred to as Standard, Chiricahua, and Arrowhead, occur commonly in the populations of this fly that inhabit Mount San Jacinto in California. It has been shown (see Year Books Nos. 39, 40, 43, and particularly No. 44) that the relative frequencies of the chromosome types undergo quite appreciable seasonal changes. Standard declines in frequency during the spring, reaches a minimum in June, and becomes again more frequent during the summer. Chiricahua, and sometimes also Arrowhead, increase in frequency during the spring, reach their maxima in June, and decline during the summer. The simplest hypothesis to account for these seasonal changes is that they are caused by natural selection; the flies with Standard chromosomes survive or reproduce more successfully than the carriers of Chiricahua and Arrowhead chromosomes during the summer, but during the spring the relations are reversed. It has proved possible to test the above hypothesis experimentally, by studying the behavior of the chromosomal types in artificial populations in the laboratory.

The Population Cages

The French biologists L'Héritier and Teissier were the first to construct "population cages," in which artificial populations of *Drosophila* can be kept under controlled conditions. A modification of their model was built in this laboratory in 1942 (see Year Book No. 43). Further improvements were suggested by Dr. C. Pavan and by Mr. Bruce Wallace. The model now in use is a wooden box 44 × 29 × 17 cm. in size, the bottom of which has 15 circular openings closed by tightly fitting corks, each of the latter carrying a glass container with culture medium. The top of the box has a glass cover so constructed that it can be replaced by another glass cover without letting out any of the flies in the cage. This detail is important, because the fly excreta soon make the glass opaque and it must be cleaned from time to time. The box rests on four legs, which are immersed in cups filled with oil to lessen the chance of infection with mites.

A desired mixture of flies is introduced into the box at the start of the experiments. Containers with fresh food are inserted, and those with worked-out food removed, at definite intervals. The fly population in the cage rapidly grows to numbers compatible with the amount of the food given, usually between 1000 and 6000 adult flies, and then fluctuates within these limits. The numbers of eggs deposited in the population cages, however, are many times greater than those of the adults produced. If the population contains two or more types with different adaptive values, the less well-adapted types are gradually supplanted by the better-adapted ones. Samples of the population are taken from time to time, usually by withdrawing a bit of the culture medium with eggs deposited on it. The larvae that hatch from these eggs are grown under optimal conditions in regular *Drosophila* culture bottles, and their salivary-gland chromosomes are examined when they reach full development. For certain special purposes (see below) samples of adult flies in the cage are taken through a metallic funnel built into one of the sides of the box.

Changes Observed in Artificial Populations

Most of the experiments completed to date have been made with flies whose

progenitors came from Piñon Flats, Mount San Jacinto, California, and at temperatures around 25° C. It has repeatedly been observed that, if the initial mixture of flies in the cage consists of 50 per cent or less of Standard and 50 per cent or more of Chiricahua chromosomes, the frequency of Standard increases and that of Chiricahua decreases with time (see experiment 22, table below, and experiment 19 reported in Year Book No. 44). Standard does not, however, replace Chiricahua entirely. Instead, an equilibrium is established at about 70 per cent Standard and 30 per cent Chiricahua.

If the initial population has 50 per cent or less of Arrowhead and 50 per cent or more of Chiricahua chromosomes, the frequency of the former increases at the expense of the latter, until an equilibrium is reached at about 70 per cent Arrowhead and 30 per cent Chiricahua (see experiment 23, table below). Finally, if the initial population contains 50 per cent or less of Standard and 50 per cent or more of Arrowhead, Standard displaces Arrowhead. The equilibrium values for this combination have not been determined. Thus, at temperatures close to 25° C., Standard chromosomes have an advantage over Arrowhead, and Arrowhead chromosomes over Chiricahua.

Professor Sewall Wright, of the University of Chicago, has analyzed the above experimental data mathematically. The simplest hypothesis which fits these data is that flies carrying two different chromosomes (structural heterozygotes) survive or reproduce better than flies with two chromosomes of the same type (structural homozygotes). If selection acts similarly in both sexes, and the adaptive value of the Standard/Chiricahua heterozygotes is taken to be 1.0, that of Standard homozygotes must be about 0.70 and that of Chiricahua homozygotes about 0.30. In other words, Chiricahua homozygotes are effectively semilethal under the conditions of competition obtaining in the population cages at temperatures close to 25° C. Since the speed of the changes observed in our experiments approximates that found in the natural populations during the summer months, it is probable that Chiricahua homozygotes are semilethal in nature as well.

It may be asked why Chiricahua chromosomes, despite the inferiority indicated by our experiments, are retained at all in natural populations. The answer is twofold. In the first place, the most favored type is the Standard/Chiricahua heterozygote and not the Standard homozygote. The selective process, consequently, does

CHANGES OBSERVED IN POPULATION CAGES CONTAINING FLIES WHOSE PROGENITORS CAME FROM PIÑON FLATS, MOUNT SAN JACINTO, CALIFORNIA. THE FIGURES SHOW THE FREQUENCIES, IN PER CENT, OF THE CHROMOSOMAL TYPES.

TIME	EXPERIMENT 22		EXPERIMENT 23		EXPERIMENT 24	
	Standard	Chiricahua	Arrowhead	Chiricahua	Standard	Chiricahua
September 19, 1945.....	20.3	79.7	20.7	79.3	89.6	10.4
Late October 1945.....	32.3	67.7	33.7	66.3	....	....
Late November 1945.....	42.7	57.3	46.3	53.7	86.7	13.3
Late December 1945.....	54.7	45.3	56.7	43.3	85.0	15.0
Late January 1946.....	....	....	....	....	80.0	20.0

not lead to complete elimination of Chiricahua chromosomes, but rather to establishment of an equilibrium at which the relative frequencies of Standard and Chiricahua are such that the average adaptive level of the whole population is the highest one attainable. In the second place, during the autumn and winter months no changes in the frequencies of the chromosomal types are observed in the Mount San Jacinto populations. This is paralleled by the observation that no appreciable changes occur in the population cages kept at 16.5° C. The adaptive values of the structural heterozygotes and homozygotes are similar, then, at low temperatures. The advantage enjoyed by the Standard chromosomes in summer is a temporary one. Furthermore, the changes that take place in natural populations during the spring months (see above) indicate that under certain conditions Chiricahua chromosomes may be superior in adaptive value to Standard. We have not yet succeeded in reproducing these conditions in our experiments.

Reversal of the Changes

The above experiments indicate that the carriers of the different chromosomal types found in Mount San Jacinto populations may have very different adaptive values. Indeed, the selective differentials suggested by these data are much higher than are customarily assumed to be operative where normal constituents of natural populations are concerned. The selection hypothesis as applied to our material must, therefore, be scrutinized very carefully. Ways to test its validity are fortunately available.

When present together in a population cage at 25° C., Standard and Chiricahua chromosomes reach equilibrium proportions at about 70 and 30 per cent respectively. This equilibrium point indicates that the adaptive value of Standard/Chiricahua heterozygotes is highest, of Standard homozygotes intermediate, and of Chiricahua homozygotes lowest. If this is correct, it follows that under certain conditions the frequencies of Standard chromosomes may be observed to decrease, and those of Chiricahua to increase, in population cages kept at approximately 25° C.: namely, the initial population of a cage must contain more than 70 per cent of Standard and less than 30 per cent of Chiricahua chromosomes. A population cage, no. 24, was accordingly started with about 90 per cent Standard and 10 per cent Chiricahua (see the table on p. 164). In about four months, the frequency of Standard chromosomes was observed to fall to 80 per cent and that of Chiricahua to increase to 20 per cent. This was not merely a change in the expected direction; its speed was also about what could be predicted on the basis of Sewall Wright's mathematical analysis.

Proportions of Heterozygotes and Homozygotes among the Eggs and among the Adults in Population Cages

Let the proportion of Standard chromosomes in a population cage be designated q, and that of Chiricahua chromosomes $(1 - q)$. If the flies carrying these chromosomes mate at random, the resulting progeny will consist, according to the well known Hardy-Weinberg formula, of q^2 Standard homozygotes, $2q(1 - q)$ Standard/Chiricahua heterozygotes, and $(1 - q)^2$ Chiricahua homozygotes. The selective processes that occur in population cages at temperatures close to 25° C. take place because the heterozygotes have a higher adaptive value than the homozygotes. The higher adaptive value may manifest itself in a variety of ways. Under the conditions of acute competition pre-

vailing in the population cages, the heterozygotes may survive more frequently than the homozygotes, or else the fecundity or the sexual activity of the heterozygotes may exceed those of the homozygotes. A differential survival would be most readily detectable experimentally, because it would lead to a disturbance of the Hardy-Weinberg ratios in favor of the heterozygotes.

The status of a population in an experimental cage is usually determined by taking a sample of eggs deposited by the flies living therein, and determining the chromosomal constitution of the larvae that grow from these eggs under optimal nutritional and other conditions. The proportions of homozygotes and heterozygotes in such samples were examined repeatedly, and they were found to agree, within limits of statistical errors, with the expectation based on the Hardy-Weinberg formula. This result shows merely that there is no appreciable difference in the survival rates of homozygous and heterozygous larvae when they develop under optimal conditions. The situation may be quite different, however, under the conditions of extreme crowding and competition that obtain in the population cages. A different sampling technique must be used to approach this problem.

The chromosomal constitution of adult flies which had developed in population cages was tested. Some glass containers in which there were numerous pupae and larvae and the culture medium had been almost entirely consumed were withdrawn from population cages 22 and 23 (see p. 164). Males and females that hatched from these pupae were separated shortly after eclosion, so that the females remained virgin. These flies were then crossed singly to individuals of the opposite sex whose chromosomal constitution was known. The salivary-gland chromosomes of six larvae were examined in the offspring of each cross. Although this procedure is laborious, it is necessary in order to determine the chromosomal constitution of adult flies collected in nature or grown in population cages. The data obtained are summarized in the accompanying table.

OBSERVED AND EXPECTED NUMBERS OF HOMOZYGOTES AND HETEROZYGOTES FOR CERTAIN CHROMOSOMAL TYPES AMONG ADULT FLIES DEVELOPED IN POPULATION CAGES. ST, STANDARD; CH, CHIRICAHUA; AR, ARROWHEAD.

EXPERIMENT 22	HOMOZYGOTES		HETEROZYGOTES
	ST/ST	CH/CH	ST/CH
Observed.....	57	29	169
Expected.....	78.5	50.5	126.0
Difference....	−21.5	−21.5	+43.0
EXPERIMENT 23	**HOMOZYGOTES**		**HETEROZYGOTES**
	AR/AR	CH/CH	AR/CH
Observed	80	58	196
Expected.....	94.8	72.9	166.3
Difference....	−14.8	−14.9	+29.7

A total of 255 flies from population cage 22 were examined. This cage contained a mixture of Standard and Chiricahua chromosomes. Among these flies, 86 proved to be structurally homozygous, and 169 Standard/Chiricahua heterozygotes. According to the Hardy-Weinberg formula, 129 homozygotes and 126 heterozygotes would be expected. So large a deviation of the observed from the expected numbers has a negligible probability of occurrence by chance. It may be considered established, therefore, that under the conditions obtaining in population cages at about 25° C. the mortality of the homozygotes is higher than that of the heterozygotes. At what stage of the life cycle the differential mortality takes place is unknown, but it seems most likely that it occurs in the larval stage.

Whether or not this differential mortality is quantitatively sufficient to account for the speed of the changes observed in the population cages is another question, which must be settled by future studies. In any case, the demonstration that the numbers of homozygotes are lower and those of heterozygotes are higher than demanded by the Hardy-Weinberg formula is important. Indeed, this demonstration affords an independent proof of the occurrence of a process of natural selection in the population cages (ignoring the possibility that the flies carrying chromosomes of different types do not interbreed at random). Knowing that the heterozygotes survive better than the corresponding homozygotes, one could predict that the proportions of the chromosomal types in the cage would be unstable.

The chromosomal constitution of 334 flies withdrawn from population cage 23 (see p. 164) was examined. This cage contained Chiricahua and Arrowhead chromosomes. The result is shown on page 166. The observed numbers of homozygotes and heterozygotes are 138 and 196 respectively, and the corresponding expected numbers are 167.6 and 166.3. The differences between the observed and the expected numbers are statistically significant. It follows that the Chiricahua/Arrowhead heterozygotes survive better than the Chiricahua and Arrowhead homozygotes under the conditions of population cages.

Experiments with Chromosomes Derived from Populations Other than That of Piñon Flats

Each of the chromosomal types found in the population of Piñon Flats occurs over a fairly large territory in the western United States and a part of Mexico. It is obviously desirable to know whether the selective differentials that exist among Standard, Chiricahua, and Arrowhead in the Piñon Flats population are to be encountered wherever these chromosomes are met with. A series of population cages has accordingly been started with flies whose progenitors were collected at Keen Camp on Mount San Jacinto, and also at Mather in the Sierra Nevada of California, some 300 miles from San Jacinto. The results of these experiments will be reported later.

Nonseasonal Changes in a Natural Population

The cyclic seasonal changes in the frequencies of Standard and Chiricahua chromosomes have been observed in the populations of Piñon Flats and of Andreas Canyon on Mount San Jacinto. Surprisingly enough, no comparable changes have been recorded at Keen Camp, even though this locality lies only some 15 miles from Piñon and Andreas (at a somewhat higher elevation) and its population of *Drosophila pseudoobscura* contains the same chromosomal types, albeit in different proportions (see Year Books Nos. 40, 44).

A different kind of change, however, has been observed in the Keen Camp population. It was noticed during the four years (1939–1942) when the populations of all three localities were sampled at regular intervals that the frequencies of Standard chromosomes seemed to increase and those of Arrowhead to decrease with time at Keen Camp, but not at the other localities. No samples were taken on Mount San Jacinto in 1943–1944. In late April 1945, Professor C. Epling kindly collected and sent to the writer population samples from Piñon Flats and from Keen Camp. The frequencies of the chromosomal types in the Piñon Flats sample proved to be what one could have expected for this season of the year on the basis of the 1939–1942 experience. But the Keen Camp

sample contained more Standard and fewer Arrowhead and Chiricahua chromosomes than was thought characteristic for the Keen Camp population. It looked as though the trend toward increase in the frequency of Standard chromosomes perceived during the 1939–1942 period had continued further and had led to a statistically significant alteration of the genetic composition of the population. To test this conclusion further, Mr. Alexander Sokoloff collected samples at Piñon Flats in March and at Keen Camp in April 1946. The composition of the Piñon Flats sample was again as expected for the season when it was collected, but a very high frequency of Standard chromosomes, and a very low one of Arrowhead, was encountered in the Keen Camp sample (see accompanying table). There seems to be no doubt that a continuous trend of change has operated at Keen Camp in the period from 1939 to 1946.

The cause of the changes observed at Keen Camp is problematic. Disastrous forest fires swept through this locality in 1941 and again in 1942. The consequent changes in the vegetation and a more arid environment may have caused an alteration of the fly population. One of the possibilities is that the fly population that inhabited Keen Camp prior to the fires died out and was supplanted by immigrants from neighboring localities, for instance from Piñon Flats. If this were the case, the new population of Keen Camp would be expected to display the seasonal changes in frequencies of the chromosomal types that are characteristic for the Piñon Flats population. Mr. Sokoloff accordingly collected and sent another sample from Keen Camp in June 1946. The composition of this sample (see table) gives no definite answer to the question at issue. The frequency of Chiricahua chromosomes was apparently higher and that of Standard a little lower in June than it was in April, but the difference is not large enough to be conclusive. It may nevertheless be considered established that changes of a more permanent nature than seasonal ones take place in the genetic composition of some wild populations. The adaptive character of these changes is probable but has not been proved.

FREQUENCIES (IN PER CENT) OF DIFFERENT CHROMOSOMAL TYPES IN THE POPULATION FROM KEEN CAMP, MOUNT SAN JACINTO

Time	Standard	Chiricahua	Arrowhead	Others	No. chromosomes examined
1939	27.8	38.3	30.4	3.5	1986
1940	31.5	41.9	22.6	4.0	2384
1941	34.7	37.1	24.1	4.1	763
1942	36.0	40.3	16.4	7.2	414
1945	41.0	29.2	22.2	7.6	288
April 1946	52.0	23.8	15.5	8.7	400
June 1946	48.0	32.5	15.0	4.5	400

RATE OF DIFFUSION OF A MUTANT GENE THROUGH A POPULATION

In 1941 and 1942 field experiments were conducted on Mount San Jacinto, to find out the rate of dispersal and certain other population constants of *Drosophila pseudoobscura* under natural conditions (see Year Books Nos. 41, 43). These experiments

consisted in releasing at a definite point in the field flies marked either with an easily visible mutant gene or with a spot of "platinum" nail polish on the thorax. For several days following the release, *Drosophila* traps were exposed at various distances from the point where marked flies had been liberated. Numbers of marked and unmarked flies that visited the traps were recorded; the resulting data permitted the calculation of the constants sought for. The drawback of these experiments is that they describe the status of the population in midsummer, when its numerical strength is close to the yearly maximum and when the dispersal rates of the flies are about the highest possible for the species. For many studies on population dynamics it would be more desirable to describe the population as it is during the period of contraction, which for most populations probably coincides with the winter months.

The Division of Plant Biology of the Carnegie Institution has very kindly permitted the writer to use some of its facilities at Mather in the Sierra Nevada of California. The unfailing hospitality of Drs. H. A. Spoehr, J. Clausen, W. M. Hiesey, and D. Keck is most sincerely appreciated.

On July 16, 1945, approximately 3840 *Drosophila pseudoobscura* flies homozygous for the mutant gene orange (bright-red eyes) were liberated at a certain point at Mather. On each of the six following days traps were exposed at 20-meter intervals, up to 600 m. north and south of the point of release. The numbers of flies visiting these traps were recorded. The results obtained make it possible to compare the behavior of orange-eyed flies at Mather with that observed earlier on San Jacinto. The rates of diffusion of the marked flies are measured in terms of the variance of their distribution over the territory surrounding the point of their release. The variances observed on successive days (in square meters) are as follows:

Days after release	Sq. m.
1	4,051
2	7,252
3	14,202
4	15,444
5	23,378
6	28,377

It may be noted that the increase in the variance of the fly distribution is approximately linear, at an average rate of slightly more than 4000 m.^{2} per day. The day-to-day fluctuations are accounted for in part by temperature changes and in part by sampling errors. The magnitude of the daily increment of variance observed at Mather is about the same as that found on San Jacinto at similar temperatures.

From July 23 to August 11, 1945, more orange-eyed flies were liberated at the same point at which the release was made on July 16. A total of about 25,100 flies were released. These orange-eyed flies became a part of the population of *Drosophila pseudoobscura* of the surrounding territory, and interbred with the wild-type flies that constituted the indigenous population. Copulating pairs in which one member had normal and the other orange eyes were observed repeatedly. Between August 12 and 16, and again between August 22 and September 5, samples of the fly population were taken at different distances from the point of release in order to determine the distribution of the orange-eyed flies over the terrain. The variance of the distribution of orange flies was estimated at as high as 88,812 and 94,202 m.^{2} This indicates an increment of variance of more than 4000 m.^{2} per day; the discrepancy is due to higher temperatures prevailing dur-

ing the later part of the summer. The orange-eyed flies found on the experimental field late in August and early in September were in part survivals of the orange flies released a month earlier, and in part their offspring, which had developed in the natural habitat. This latter point was proved not only by finding some orange-eyed individuals which from their external appearance were judged to be young flies, but also by discovering that flies heterozygous for orange genes were present in the same neighborhood. The presence of heterozygotes is ascertained by crossing normal-eyed flies collected in the field to homozygous orange flies in the laboratory. If the wild fly being tested contains no orange, the entire offspring of the cross consists of wild-type flies; if it is an orange heterozygote, approximately half of its offspring are orange and the other half are wild-type flies. It is certain, therefore, that the orange gene has entered into the genetic composition of the Mather population.

During the summer of 1946, flies were collected at Mather in the vicinity of the point at which orange flies had been released a year before, as well as approximately 500 m. and 1000 m. north and south of this point. All the flies had normal (non-orange) eyes. Nevertheless, it proved possible to ascertain the presence of the orange gene in this population by making the above-described test crosses of the wild flies to the orange mutants in the field laboratory organized at Mather. Among the flies caught in the vicinity of the point of release, about 2.8 per cent of the third chromosomes carried the orange gene. At 500 m. from the point of release, the percentage of orange-carrying third chromosomes dropped to 1.7, and at 1000 m. to 0.4. After correction for the natural occurrence of orange heterozygotes, these figures lead to an estimate of variance of the order of 208,265 m.^{2} Even though this estimate has a very large probable error, the conclusion is inescapable that the fly population is rather stationary, and particularly that relatively little further diffusion of the orange gene took place at Mather between August-September 1945 and June 1946. A more detailed analysis of the data will be made at a later date.

Sexual Reactions of Drosophila subobscura, D. persimilis, and D. pseudoobscura

These three species are similar in appearance, the latter two being practically identical morphologically. Nevertheless, their distinctness is maintained by several isolating mechanisms, among which sexual isolation is one of the most effective. In the case of *D. persimilis* and *D. pseudoobscura,* males of one species, when confronted with a choice of females of both, inseminate principally their own females, and this regardless of whether they are in light or in darkness. Rendel, Spurway, and Haldane found that *D. subobscura* requires light for mating, the cultures placed in the dark remaining sterile. Mr. Bruce Wallace and the writer have confirmed the findings of the above investigators as far as *D. subobscura* itself is concerned. Furthermore, when *D. subobscura* males are placed in the dark with *D. persimilis* or *D. pseudoobscura* females no inseminations take place. In the light, some cross-insemination takes place. *D. pseudoobscura* or *D. persimilis* males inseminate some *D. subobscura* females in the light as well as in the dark. Direct observations have shown that males of these species court females of their own and of foreign species with about equal frequency (*D. subobscura* males do so, of course, only in the presence of light). The difficulty in cross-insemination arises either at the time when the male tries to mount

the female, or after the beginning of copulation, when the female forcibly dislodges the male. Insemination occurs apparently only in those instances when the male succeeds in maintaining his position for a time somewhat longer than the average.

MOUSE LEUKEMIA

E. C. MacDowell, J. J. Biesele, G. Gasić, R. A. Miller, and M. J. Taylor

Variation in Chromosome Size

In an attempt to define more closely the problems of chromosomal enlargement in malignancy, Biesele has contributed further evidence to the conclusion suggested last year that the increased size of the chromosomes of mouse leukemias, and supposedly of other neoplasms as well, depends upon increases at the molecular level of organization, rather than at the level of the chromatid.

The most decisive new evidence for this conclusion was gained from a study of the shrinkage of chromosomes in tissue sections partially digested by pepsin. Chromosomal shrinkage in acidic pepsin solution has been interpreted by several authors, in particular by Mazia, as resulting from digestion of a complex acidic protein, with subsequent contraction of the residual chromosomal components, especially histone. Using commercial pepsin, as well as crystalline enzyme kindly provided by Dr. M. R. McDonald, it was found that the shrinkage of chromosomes in long-transplanted lines of leukemic cells was proportionally greater than that of chromosomes of normal lymphocytes, so that most of the difference was erased. Similarly, the shrinkage following pepsin digestion of the large chromosomes of newborn mice was nearly as great as that of leukemic chromosomes. After subjection to pepsin, the chromosomes in all cases were brilliantly colored by Feulgen's test for desoxyribose nucleic acid.

Direct evidence against an increased number of chromatids in neoplastic chromosomes as the explanation of their greater size was obtained from a comparison of uncoiled chromosomes in normal lymphocytes and in leukemic cells of the six current lines. The tissue was minced in dilute alkaline solution and pressed out in acetocarmine. Metaphase chromosomes of both normal and neoplastic cells included only two chromatids, which cohered at but one point (the centromere). So far as could be detected with the light microscope, the leukemic chromosomes, though larger, were no more complex in structure.

It appeared, then, that different quantities of pepsin-digestible protein might explain much of the difference in volume between normal and leukemic lymphocyte chromosomes. A search has yet to be made, be it noted, for possible qualitative differences in the pepsin-digestible protein in the two cases.

This hypothetical pepsin-digestible protein may be equivalent to the acidic protein, chromosomin, that Stedman claims is the main component of chromosomes and particularly abundant in isolated nuclei of carcinomata, or to the complex tryptophane-containing protein that Mirsky, Pollister, and Ris have found in normal chromosomes, varying in proportional amount according to the cell type. Considerably more of this tryptophane-containing protein was present in isolated chromosomes of mammalian liver than in chromosomes of the thymus. Biesele observed the chromosomes of liver to be larger than those of thymus in both rat and mouse.

However, the probability that other constituents vary in amount is also to be

considered. It is difficult to imagine that histone, for example, is equal in amount in metaphase chromosomes that differ in average volume 20 or 30 times, for example those in embryonic thymus as compared with those in senile liver of the rat. Marshak and Walker have found a considerable quantity of firmly bound lipoid in liver chromosomes of adult rats.

The weight of evidence at present relates variation in the size of chromosomes of normal tissue to the functional state of the cell. Periods of differentiation, or modulation within a differentiated state, and changes in vitamin B concentration and hormone balance have all been associated with changes in chromosome value. A preliminary report was given last year of chromosomal changes in leukemic lymphocytes depending upon alteration of the sexual hormones of the hosts. This study has now been extended to the chromosomes in line-I and line-Ia leukemic cells in 92 hosts in four experiments. Chromosomes of the largest sizes were found in males, with or without implanted pellets containing testosterone propionate, and in females with such pellets, whether ovariectomized or intact; intermediate sizes were found in intact females without pellets; and the smallest sizes, only slightly greater than those in normal lymphocytes of adult mice, were found in ovariectomized females without pellets. Normal lymphocytes, however, responded differently to the hormonal treatment. Gonadectomy of adult females by itself did not lead to a change in size of lymphocyte chromosomes; but in gonadectomized females given pellets of testosterone propionate, if any change occurred it was toward a diminution of chromosome volume, rather than the increase shown under these conditions by leukemic chromosomes. This effect was in line with the reduction in chromosome size after puberty that Biesele observed in lymphoid tissue of both rats and mice.

From the late embryo to the newborn mouse there was a slight increase in average chromosome volume; thereafter, a gradual drop occurred, which leveled off with full maturity at a value perhaps half that in the newborn animals. In the cells of spontaneous leukemia there was a slight rise in average chromosome volume corresponding in value to that given by normal lymphocytes in animals two months old. During the first eleven transfers of one new line of leukemia there was a gradual increase in chromosome size, from that found in newborn mice to that found in long-transferred and highly virulent lines; in a second new line this transition was completed by the fourth transfer. Later, to judge from the behavior of these two new lines as far as their twenty-second and twenty-fifth transfers and from the old lines being carried in this laboratory, little further change in chromosome volume would be expected, despite the multifarious changes in other respects that these two lines might undergo. There remained, of course, plasticity in response to environment, such as was manifested in the hormone study.

The problem of the significance of chromosome volume in neoplastic and normal cells grades into other problems: the functions in cell economy of pepsin-digestible protein and of the other components of chromosomes; the meaning of their variability in amount and, possibly, in specific nature; the relation of changes in them to alterations in other parts and activities of the cell.

Variation in Mitochondria

The growing interest in mitochondria, as well as the current emphasis upon changes in lines of transplanted leukemia,

prompted Miller to compare the present numbers of mitochondria in certain lines with the counts made by Potter and Ward five years ago. At that time the average number of mitochondria per cell was significantly above normal for the various leukemic populations studied. This condition was accompanied by a shift of the modes and upper limits of the frequency distributions, although the lower limit in all cases coincided with that of the normal distribution. Among leukemic cells, the relatively avirulent spontaneous leukemias gave the lowest averages; line I, killing in 4 days, gave a significantly higher average, and line U, killing in 7–15 days, gave the highest average of all. Since these counts were made, line I has not changed in respect to length of the interval before death, whatever other changes it may have undergone, but line U now kills in 4 days. With this change in line U, Miller reports that the number of mitochondria, instead of being reduced to resemble line I, has greatly increased. Previously the average for line U exceeded that for line I by 2.3 (5.7 × S.E.); the difference between the current counts for line I and line U is 29.8 (31.7 × S.E.). Although the technique described by Potter and Ward was followed as closely as possible, Miller's counts both for normal lymphocytes and for line I are higher than previously reported. This appears in the averages and the modes of the frequency distributions, as well as in a considerable asymmetrical trailing off of the upper limits, which is also shown by line U. The total range for each of the three cases, as recorded by Miller, is more than double the previous ranges; the lower limits, however, are still nearly the same.

Anucleate Lymphocytes

While counting mitochondria in leukemic blood, Miller became interested in certain anomalous, anucleate structures which, although not mentioned by previous observers, appeared in blood carrying each of the current lines of transplanted leukemia, as well as in blood from spontaneous cases, but were entirely absent from normal blood of mice from the same strain. As a feature of leukemic blood, these bodies demanded study. Accordingly, in recent weeks, Miller has investigated their morphology and distribution.

The appearance of these bodies in various preparations (Janus green and neutral red, Wright's stain and Feulgen technique) favors the interpretation that they represent lymphocytes that have lost their nuclei. They are rounded, cell-like masses with a firm, intact edge, varying in diameter from 2 to 12 microns. Thus some are twice the size of a red cell, and they are not destroyed by the dilute acetic acid used to eliminate red cells in counting leukocytes. The cytoplasm resembles that of lymphocytes in its granular structure, in its clear vacuoles, and in its basophilia. It differs from that of red cells in showing no yellow tint or violent Brownian movement. The mitochondria and neutral red granules resemble those of lymphocytes in being larger and more densely staining than those of polymorphonuclear leukocytes. In blood carrying leukemic cells of line I, the mitochondria of the anucleates have the morphological characteristics that distinguish the mitochondria of this line from those of other leukemic lines and from normal.

The absence of a nucleus is verified: (1) in supravital preparations, by the visibility of the unstained nuclei in adjacent lymphocytes; (2) in smears with Wright's stain, which fail to reveal a nucleus but occasionally show an area of the cytoplasm less heavily granulated and less densely stained, similar in size, shape, and position to a lymphocyte nucleus.

The probability that these anucleates arise from lymphocytes is considerably increased by the appearance of a series of stages of nuclear disintegration—from lymphocytes with a small and pycnotic nucleus, down through nuclear fragments, to anucleates with one or more fine granules taking the nuclear stain. In Feulgen preparations, inclusions of similar morphology gave a positive test for thymonucleic acid. The cells with large nuclear fragments were recorded separately as "degenerating" and not included with the anucleates in calculations.

The relative frequency of anucleates and lymphocytes at the terminal stage varied with the line of leukemia: lines I, M liv, and W gave respectively 29, 24, and 22 anucleates per 100 white cells; lines U and V, 14; line L, 10; and line S, 3. This variation is not correlated with other recognized line characteristics such as virulence. The proportion of degenerating nuclei to anucleates in five of the lines, ranging from 1.0 (V) to 3.4 (S) per 100 anucleates, may not be significantly different. But in line W, this proportion went up to 15.5 per 100 anucleates. In one series of daily observations with line I, the proportion of anucleates in the peripheral blood progressively increased, in the four days between inoculation and death, from about 4 to 28 per 100 white cells. The anucleates appeared in 24 hours, although the total-white-cell count on the first day after inoculation was, as usual, below normal and did not reach leukemic numbers till the last day. The proportion of anucleates seems to be independent of factors responsible for the variation in the total-white-cell count at the terminal stage. When, however, the interval before death was prolonged by using a dilute dose of leukemic cells (line I, 4^{-5} × standard), the terminal proportion of anucleates was sharply reduced (from 29 to 17 per 100 white cells). At the same time the total white count was considerably higher than at the corresponding stage with the stronger dose. It should be noted that the dilute dose reduces the inflammatory lesions and permits larger amounts of leukemic growth before death occurs.

In mice resisting a lethal dose of line I as a result of a previous treatment with normal tissue from strain StoLi, the proportion of anucleates in the blood was strongly reduced at all times as compared with the untreated controls, although the observations were made with the thought that the destruction of lymphocytes known to take place at a certain stage of this resistance might increase the appearance of anucleates.

Without commenting on the various interpretations that are suggested by the foregoing observations, it should be noted that Miller finds anucleates in photographs made by Potter five or more years ago.

Local Resistance

The particular interest of Gasić in the alarm reaction that, as he has shown (Year Book No. 44, p. 136), may be provoked by transplanted leukemias lay in the possibility that it might play a part in the phenomena of induced resistance to leukemia. Selye, who is identified with the term "alarm reaction," considered this to be a part of a general, nonspecific defense process, by which other deleterious stimuli may also be resisted. Could an alarm reaction induced by a nonleukemic stimulus prevent the appearance of the alarm reaction induced by inoculating leukemic cells? As an approach to this question, Gasić attempted to demonstrate this state of general defense with formalin and adrenalin—stimuli extensively employed by Selye. However, unexpected evidence of local, rather than general, resistance appears to have removed the basis for the question.

With subcutaneous administration throughout, the lethal doses of formalin and adrenalin were found to differ according to the region of the body, of which eight were designated. After four preliminary sublethal doses of the same or increasing strength, either in the same or in different sites, the results with formalin varied according to the site of the final lethal dose. If this was given at a site previously used, the mice survived; if in a region of the body not previously treated, the mice died. The same was true when the cross-resistance to the lethal dose of adrenalin was tested.

The animals pretreated with adrenalin reacted somewhat differently. They could resist the lethal dose of adrenalin even when it was administered in a body region not previously treated, but to the lethal dose of formalin they offered no resistance even when all the pretreatments and the formalin were given in the same site. Thus the resistance induced by one drug is nonspecific, and that induced by the other is widespread; but the nonspecific resistance is local and the widespread is specific.

Although local resistance is not frequently encountered, it is not a new phenomenon. Rosenthal, Tabor, and Lillie observed that mice surviving tourniquet shock because of salt treatment survived a repetition of the same shock, without salt, if it was given to the same leg; but if it was given to a different leg, they died. Similarly, according to a review by J. Levy, animals in which resistance to arsenic has been built up *per os* do not tolerate a toxic dose administered subcutaneously.

Even if the general, nonspecific resistance described by Selye has not been found in the particular strain of mice here employed, and if the widespread distribution of leukemic cells seems at first to preclude resistance phenomena of a local nature, it is still possible that the induced resistance to leukemia under consideration resides only in those tissues with which the leukemic cells in the immunizing doses have come into immediate contact.

Adrenalectomy

The adrenal gland is known to play an important part in certain familiar immunological reactions, by permitting the involution of the thymus, the destruction of lymphocytes, and, thereby, the liberation of antibodies that they may carry. Gasić considered that this offered a method for investigating the nature of the mechanism responsible for the resistance induced by certain leukemic cells against themselves. If this resistance employs antibodies harbored by normal lymphocytes, removal of the adrenals might be expected to break down the resistance. A difficulty with this approach is the fact that the adrenalectomy in itself may cause death, so that an increase in the deaths of immunized mice might not be an indication that the mechanism of resistance to leukemia had been broken down by adrenalectomy. Before such a conclusion could be drawn it would be necessary to show that the time of death and the pathological conditions at autopsy were the same as for nonimmunized, adrenalectomized mice. In carrying out such a test, Gasić took advantage of a remarkably useful property, only recently discovered, of line L, namely, that only a single, moderately dilute dose (1/256 of standard) is required to induce resistance to a lethal dose. Thirty days after such an immunizing dose Gasić performed adrenalectomies, and on the following day he inoculated with a full standard dose of this line (L). The most important controls were the adrenalectomized mice given the standard dose without immunization; these showed that the removal of the gland had no appreciable effect upon the ter-

minal weight of the organs most heavily infiltrated by the leukemic cells, when compared, at the same interval after inoculation, with organs of intact mice. The removal of the gland, however, hastened death in most cases, so that the leukemic growth was correspondingly cut short; this accounts for a reduction in the average weights of spleen and liver at death.

In a group of 21 adrenalectomized mice the effect of the immunization was manifested by the survival of every one for at least 4 days beyond the death (4 days, 22 hours) of the last of 16 nonimmunized, adrenalectomized controls. Within the following 4 weeks 9 died, but the weights of liver, spleen, and nodes of these mice were considerably less (not even overlapping) than those of the nonimmunized controls, and the general autopsy picture was dissimilar, whereas, on all these points, there was close similarity to the 5 mice (out of 15) that died from adrenalectomy alone. It seems probable that adrenalectomy and the consequent noninvolution of the thymus has had no effect upon the mechanism of resistance induced by line-L leukemia, a conclusion that agrees with previous evidence indicating that such resistance is not due to circulating antibodies.

MAIZE GENETICS

BARBARA MCCLINTOCK

CONTINUATION OF THE STUDY OF THE INDUCTION OF NEW MUTANTS IN CHROMOSOME 9

The study of the induction of new mutants in the short arm of chromosome 9, following the chromatid and chromosome breakage cycles involving this arm, is nearing completion. At present, nine new mutant types have been isolated that are located in the short arm of chromosome 9. The mutants pale-yellow seedling (*pyd*), white seedling (*wd*), and yellow-green seedling and plant (*yg*) have been repeatedly induced by the breakage-fusion cycles. Only one each of the following mutants has been obtained: bronze aleurone, virescent seedling, pale-green seedling, small-kernel, narrow-leaf, and light-green plant. Only in one branch of this study was an attempt made to determine the proportion of all newly arising seedling or kernel mutants that are located in chromosome 9. Three hundred and eighty-three plants that showed the chromosome type of breakage cycle in their early developmental stages were self-pollinated and the kernels and seedling progeny observed. Thirty-two newly arising stable (nonvariegating, see below) recessive mutants were observed. Twenty-four of these were located in chromosome 9 (5 *pyd*, 11 *wd*, 5 *yg*, 1 small-kernel, 1 narrow-leaf, 1 light-green); four of the new mutants were not located in chromosome 9, although one of them showed an unexpected relation to a previously known mutant in chromosome 9; tests of the four remaining new mutants have not been completed. In the majority of the parent plants, only one of the two chromosomes 9 could be thoroughly tested for the presence of a new mutant, because of the frequent lack of transmission through the pollen of one of the altered chromosomes 9.

Cytological observations of the chromosome 9 carrying a newly arising mutant have been made in the case of 13 *pyd* mutants, 11 *wd* mutants, 8 *yg* mutants, and the small-kernel, pale-green, and bronze mutants. In 12 of the *pyd* mutants, all of the *wd* mutants, the bronze mutant, and the small-kernel mutant, a chromosomal deficiency or an obvious alteration was evident at the "locus" of the mutant.

In the remaining cases examined, the particular chromosomal event that gave rise to the mutation could not be determined with certainty.

One of the four new mutants not located in chromosome 9 showed an interesting relation to the mutant *c*, which is located in the short arm of chromosome 9. The recessive mutant *c*, when homozygous, produces kernels that have no color in their aleurone layer. The dominant allele, *C*, gives rise to colored aleurone. The new mutant, a simple recessive in breeding behavior, produces small kernels with defective embryos. Plants that were *Cc* and likewise heterozygous for the small-kernel mutant were self-pollinated. Colored and genotypically colorless (*cc*) kernels and normal and small kernels segregated independently. The small kernels in the homozygous *cc* class, however, were not completely colorless, as expected. Instead, they showed a faint but distinct blush of color in the aleurone layer, closely resembling that produced by the *bz* mutant. Cytological examination has not been made to determine whether the origin of the small-kernel mutant may have involved chromosome 9 in some unusual manner. The peculiar relations of the spotted-leaf mutant, as described below, suggest this possibility.

Modification of Mutant Expression Following Chromosomal Translocation

The recessive mutant "spotted-leaf" (*spl*), in early investigations, gave evidence indicating that it was a recessive located in the short arm of chromosome 9. This was because the spotted-leaf character appeared in the appropriate chromosomal class in F_1 plants following the cross of a spotted-leaf plant to a female plant heterozygous for a relatively long but transmissible terminal deficiency of the short arm of chromosome 9. Further study of this particular mutant revealed that its inheritance is not typical of a simple recessive and that its locus cannot be placed in the short arm of chromosome 9 in the usual manner.

The spotted-leaf mutant is not detected in the young seedling stage. Chlorophyll development in the seedling usually appears quite normal. As the plant continues to grow, the chlorophyll throughout the plant changes to a bright yellowish green. Later, further changes in the chlorophyll occur. In evenly distributed, small spots throughout the leaves, the chlorophyll appears to break down still further. Thus, on a light-green leaf there appear many small yellowish spots. The mutant has consequently been called "spotted leaf." Following the production of the spots, the plant may exhibit various degrees of necrosis of the cells of the leaf, beginning at the tips of the leaves. This degeneration is accelerated by excessive heat and light. Relatively few spotted-leaf plants have survived to maturity.

The spotted-leaf mutant first appeared in the progeny of a self-pollinated plant that was being investigated for purposes other than the detection of new mutants. This parent plant had one chromosome 9 with the minute terminal deficiency that, when homozygous, produces pale-yellow (*pyd*) seedlings. This chromosome 9, of known constitution, had been introduced into the parent plant by a controlled cross. Its homologous chromosome 9 had previously been altered in constitution following a series of breakage cycles. During these breakage cycles, an additional chromosomal alteration occurred. It involved the translocation to the end of the short arm of chromosome 8 of a segment composed of six chromomeres derived from the end of the short arm of chromosome 9.

As this segment of chromosome 9, before its translocation to the short arm of chromosome 8, had been subjected to the breakage-fusion cycles, it was not an unmodified terminal segment. Its exact composition is still unknown. Cytological observations indicate that chromosome 8 could not have lost more than a chromomere from the tip of its short arm during the translocation process; if as much chromatin as this has been removed, the resulting deficiency does not interfere with pollen transmission to a marked extent, for this chromosome is readily transmitted through the pollen. (Translocations involving the broken end of chromosome 9 during its chromatid breakage cycles with other chromosomes of the complement are not infrequent. See Year Book No. 41.) The parent plant had, then, a *pyd* chromosome 9, the newly modified chromosome 9, a normal chromosome 8, and the chromosome 8 with the translocated segment. This plant was normal in appearance. The new spotted-leaf mutant as well as the expected *pyd* mutant appeared in the progeny of this plant following self-pollination.

All evidence to date indicates that the spotted-leaf character will appear whenever a plant is homozygous for any one of the *pyd*-producing deficiencies of chromosome 9 and also has one normal chromosome 8 and one chromosome 8 with the translocated segment. In other words, the chromosome 8 with the translocated segment is responsible for the appearance of the mutant spotted-leaf, but only when a short terminal homozygous deficiency is also present in chromosome 9. A simple interpretation, subject to verification, of this relatively complex genotypic expression is possible. The terminal deficiency that produces the *pyd* mutant is large enough to be cytologically detected. Possibly the segment of the tip of chromosome 9 that has been translocated to chromosome 8 is itself incomplete and has a very minute deficiency for a segment of chromatin within the limits of the larger *pyd*-producing deficiency. Thus, plants having two deficient *pyd* chromosomes 9 and the duplication carried by chromosome 8 would be homozygous deficient for a minute segment of chromosome in the tip region of chromosome 9 even smaller than that which produces the *pyd* character. If this is so, the spotted-leaf character would be expected to appear as a simple recessive mutant, located close to the tip of the short arm of chromosome 9, in the progeny tests of some plants whose chromosomes 9 have undergone the breakage cycles. It would be expected to show allelism with the *pyd* and *wd* mutants. That it has not been detected so far in progeny tests of such plants may be due to the difficulty of detecting this mutant in the seedling stages, which have been used almost exclusively for detecting the newly produced mutants.

The known conditions connected with the origin and action of the spotted-leaf phenotype are instructive in a consideration of the problems associated with some previously studied types of interrelated but independently inherited mutant factors. A succession of a few relatively simple chromosomal aberrations may well account for some of these observed relations.

The Unexpected Appearance of a Number of Unstable Mutants

In the cultures that were grown to observe the mutations produced as a consequence of the breakage cycles of chromosome 9, an unusual and unexpected series of new mutants appeared, characterized by types of instability known in genetic literature as mutable genes, variegation, or mosaicism. Although maize has been ex-

tensively investigated, the appearance of "mutable genes" has been relatively rare. In the present comparatively restricted study of the progeny of plants having newly broken chromosomes 9, fourteen distinctly new expressions of instability of genic action have been isolated, although more types have been observed. Six of these have received at least preliminary investigation. It is not possible, however, to follow the genetic or cytological factors associated with all these new variegated types, because of the extensive amount of time and labor involved in the study of any one. The plant characters that may be most readily detected in variegated or mosaic patterns involve some form of color change in a tissue. Thus, most of the variegating types that have been recognized involve either anthocyanin or chlorophyll pigments. It should be emphasized that no one of these variegating mutants has received more than a preliminary study; however, a brief description of four of these mutable types will serve to illustrate the nature of the phenomena and the problems involved.

Variegated white seedling. This mutant first appeared in the progeny of a self-pollinated plant in which both chromosomes 9 had been involved in the chromosome type of breakage cycle in the very young embryonic stage. This first progeny consisted of 108 normal green seedlings and 19 white seedlings. In the white seedlings, sectors of pale-yellow or of normal-green tissue were present. Each pale-yellow or green sector was sharply delimited; all the plastids in the pale-yellow cells were yellow and all the plastids in the green cells were normal green. The size of the pale-yellow sectors varied from large, indicating an early mutation from white to pale-yellow, to very small, indicating a late mutational change to pale-yellow. Most of the green sectors were small, indicating that the mutations to green usually occur late in the life of the tissue. A few early mutations occurred, however, as there were a few rather wide green sectors in the leaves of some of these white seedlings. The rate of mutation to pale-yellow and to green in any one seedling was relatively constant; in general, each seedling was distinguished by one particular rate of mutational change. In some of the seedlings, distinct sectors were present in which the rate of mutation had increased considerably, although within these well defined sectors themselves uniform rates of mutation were discernible. This variegating mutant behaved as a simple recessive upon further testing. The phenotypic expression of the variegation—that is, white, pale-yellow, and green—is strikingly similar to the allelic series composed of *wd, pyd,* and normal-green associated with overlapping deficiencies at the tip of the short arm of chromosome 9. A further similarity to the *wd* mutant is apparent: when plants heterozygous for this variegating white mutant are selfed, a number of kernels with defective embryos are produced. If the proportion of kernels with defective embryos is high on any one ear, the expected proportion of variegated white seedlings is correspondingly lowered. In each case, the total number of defective embryos plus white-variegated seedlings approximates the one-fourth expected in the progeny. This behavior is quite similar to that of the *wd* mutants that have been extensively studied. Nevertheless, when this mutant is combined with the *wd* mutants, only normal-green seedlings and plants are produced. Furthermore, tests have shown that this mutant is not located in the short arm of chromosome 9.

Variegated light-green. The recessive light-green mutant appeared in the progeny of a self-pollinated plant that had received a chromosome 9 which had been under-

going the chromatid type of breakage cycle. Approximately one-fourth of the seedlings in this progeny were very light green. All the light-green seedlings showed a number of sectors of normal-green tissue, most of them appearing as fine green streaks in the light-green leaf. In the cells that are light green, the plastid size and number are normal but the chlorophyll color in all plastids is light green. In the sectors of normal tissue, the chlorophyll in all plastids is normal green in color. In any one seedling, the mutations to normal green occur at an approximately constant rate. Very wide differences, however, appear among the various seedlings; some have very high rates of mutation, others have very low rates, with many seedlings showing gradations between these extremes. These definite rates of mutational change from light green to normal green are maintained throughout the life of an individual plant, except for distinct sectors, presumably arising from individual cells, that show an increased rate or a reduced rate of mutation, respectively, over that of the plant as a whole. In a number of cases, two distinctly delimited but adjacent sectors showed inverse relations in their mutation rates. In one sector the rate of mutation, as expressed by the number of green streaks in the leaf tissue, was greatly increased, whereas in the sister sector the number of green streaks was greatly reduced. The positions of these twin sectors in the stalk and leaf suggested that they arose from two sister cells of the growing point. Such striking changes in the rate of mutation of cells derived from a single somatic cell of a plant have characterized all the variegating types that have been under study. The yet-unknown alteration that occurs in this cell determines the rates of mutation of the recessive mutant to a dominant allele in all cells that arise from it, until another such change suddenly occurs. The frequent appearance of twin sectors showing inverse rates of mutation leads to the suggestion that the controlling factor for future mutational occurrences may be altered or segregated at a somatic mitosis so that the mutations that will occur in the cells arising from one daughter cell are increased over the potential rate of the mother cell; conversely, the mutations that will occur in the cells arising from the other daughter cell are reduced.

The light-green character is inherited as a simple recessive. In individual cultures, the F_2 ratios frequently approximate three normal-green plants to one light-green plant. This usually occurs when the mutation rates in the light-green plants are uniformly low. However, in some F_2 cultures segregating light-green plants with low mutation rates, the ratios were distinctly aberrant. When the mutation rates are high in the light-green plants of an F_2 culture, a deficiency in the light-green class frequently occurs. This suggests that mutations of the light-green locus to normal green have occurred at a relatively high rate in the F_1 heterozygous plant and result in an increase in the relative number of gametes carrying normal green. It is possible that the light-green locus may occasionally mutate to intermediate alleles, as several distinctive types of the light-green mutant have appeared in a few of the cultures.

The luteus mutant. The recessive luteus mutant is one of the more interesting and complex of the variegating mutants that have appeared in this study. The luteus character is associated with the presence of small yellowish plastids. The luteus seedlings are, therefore, bright yellow. From one original plant that had received a chromosome 9 which had undergone the chromatid type of breakage cycle, two kernels were removed and plants were grown from them. Each plant was self-

pollinated. In the progeny of one plant, yellow (luteus) seedlings segregated. These showed no variegation. In the progeny of the second plant, yellow seedlings segregated but many were highly variegated for normal-green tissue. The nonvariegated luteus seedlings from the first plant were inviable, but the more highly variegated luteus seedlings from the second plant were viable, presumably because of the extensive amounts of normal-green tissue. Further tests showed that the nonmutating or stable luteus and the highly mutating luteus represent two extreme states of one particular locus. The stable luteus is only relatively stable and, in the tests so far conducted, has only rarely become mutable again.

In F_2 progeny tests, stable luteus usually segregated quite normally. From 52 self-pollinated F_1 plants there were obtained 2306 normal-green seedlings, 773 nonvariegated luteus seedlings, and only 3 variegated luteus seedlings. These 3 variegated luteus seedlings appeared in three different cultures. In one single F_2 culture, 231 normal-green seedlings, 51 nonvariegated luteus seedlings, and 10 variegated luteus seedlings appeared. In this case, it is probable that in a cell of the F_1 heterozygous plant the stable luteus suddenly became unstable and formed a sector of mutating luteus. In contrast with the stable luteus, the highly variegating luteus is distinguished by great instability of the luteus locus. It may mutate to normal green but also, phenotypically at least, to several distinctive intermediate alleles.

Plants heterozygous for the highly stable luteus and a mutating luteus may exhibit various rates of mutability in a manner quite similar to that observed among the variegated white seedlings and the variegated light-green plants. A distinctive and relatively constant rate of mutation from luteus to green is apparent in each individual seedling. These rates range from very low, with only a few small green streaks on a leaf, to very high, where the leaf appears to be almost mottled because of the many mutations that have occurred. Most of the mutations occur late in the development of the tissues, but a few occur earlier and give rise to wide sectors of light-green or normal-green tissue. In a manner quite similar to that found in mutable white and light-green, distinctive sectors appear in these plants with decidedly altered rates of mutation, either increased or decreased. Adjacent sectors (twin sectors) also occur, one showing an increased rate of mutation, the other a reduced rate of mutation as compared with that in the plant as a whole.

A further complexity also appeared. It was first clearly recognized in the progeny resulting from a cross of plants that were heterozygous for a stable luteus locus and its wild-type allele by the variegated luteus plants that had both a mutating and a stable luteus locus. Because the F_1 plants resulting from the combination of either a stable luteus or a mutating luteus with a normal wild-type allele have been normal green in appearance, one could expect to find normal-green plants, variegated luteus plants, and nonvariegated luteus plants in the progeny of the above cross. These three types of plant appeared, but, in addition, a distinctly new type of variegated plant was present. These plants were green but showed fine streaks of luteus. The numbers of such streaks varied greatly among the different plants. When very many streaks were present, they occurred in well defined sectors within the leaf. In a few of these plants, wide sectors of luteus were present. Within some of these luteus sectors, mutations to normal green occurred, each sector showing its own particular rate of mutation from luteus to green. Because these plants were mainly

green, with fine streaks of luteus, they were designated "streaked." In their patterns, the streaked plants resembled the variegated luteus plants, but they were reverse images—that is, negatives (luteus streaks in green tissue)—of a positive (green streaks in luteus tissue) variegation pattern. This suggests that some of the mutations of luteus to green are unstable and revert to luteus by processes similar to those that give rise to the dominantly directed mutations. As a working hypothesis, to be considered as tentative only, it may be conceived that the locus concerned may be present in a very stable recessive state, rarely mutating to dominant, or in a very stable dominant state, rarely mutating to luteus; or that it may be present in recessive or dominant states with various intermediate rates of mutability. Furthermore, changes in the stability of any one state may occur suddenly, following some yet-unknown event that probably takes place during a mitosis.

The chromosome-breakage variegation. The most unexpected expression of variegation that has appeared in these investigations is associated with the occurrence, in many somatic cells, of breakage in chromosome 9 that takes place at a particular locus in the short arm of this chromosome. This breakage results in the formation of an acentric fragment and the subsequent elimination of this fragment at a somatic anaphase. This phenomenon first appeared in the progeny of a self-pollinated plant that had started development with its two chromosomes 9 undergoing the chromosome type of breakage cycle, although healing of the broken ends had occurred in early embryogeny. A few of the kernels on the ear of this plant exhibited a type of aleurone color variegation that had not previously been observed. In this plant, one newly broken chromosome 9 carried the factors *I* (dominant inhibitor of aleurone color) and *Wx* (starch in endosperm stains blue with iodine). Its homologue carried the recessive alleles *i* (colored aleurone) and *wx* (starch stains red with iodine). The aberrant kernels were recognized in the heterozygous class that had received both the *i*- and the *I*-carrying chromosomes. According to their genetic constitution, such kernels should be colorless. The aberrant kernels were conspicuous because of the presence of colored (*i*) areas. In some kernels, there were well defined sectors that exhibited a uniform pattern of small *i* spots. The pattern in any one such sector was distinguished by the number of *i* spots, their uniform distribution within the sector, and their relatively similar size. The patterns in these sectors suggested that the *I* factor, carried by one chromosome 9, had been systematically eliminated from some cells and that, in each sector, this had occurred at a particular rate and at a particular stage in the development of the endosperm tissue. Subsequent testing indicated that the *I*-carrying chromosome also possessed the minute terminal deficiency that is responsible, when homozygous, for the appearance of white seedlings (the *wd* mutant). Consequently, green and white seedlings segregated in the progeny of this self-pollinated plant, the white seedlings arising mainly from the *I* kernels.

To investigate the nature of the phenomenon associated with the appearance of the *i* spots, the green plants arising from some of the *I* kernels were grown in the summer of 1945. In many of these plants, fine streaks of white tissue, rather uniformly distributed over the leaf, were observed. In some plants, there were only a few such non-chlorophyll-bearing white streaks; in others, there were more; in one plant, the number of white streaks was relatively large. In most of the plants, dis-

tinct sectors were present in which the number of uniformly distributed white streaks was greatly increased or decreased over that of the plant as a whole. In these aspects, the patterns of variegation resembled those observed in the three previously described variegating types.

In agreement with the presence of the *i* spots in some of the *I* kernels, the presence of white streaks in the leaves of many of the plants again suggested that a segment of chromatin of one chromosome 9 was being systematically eliminated in somatic cells. Elimination from one chromosome 9 of the chromatin segment that covers the white-producing deficiency in the other chromosome 9 would allow the non-chlorophyll-producing effect of this deficiency to be expressed. According to this interpretation, it would be necessary for the streaked plants to be heterozygous for the *wd* mutant. Tests confirmed the presence of the *wd* mutant in all the streaked plants.

The white-streaked plants used for further crosses carried *wd, I, Bz, Wx* in one chromosome 9 and *Wd* (i.e., chromatin segment covering the white-producing deficiency), *i, Bz, wx* in the homologous chromosome 9. Pollen of these streaked plants was placed on silks of plants carrying various recessive mutants located in the short arm of chromosome 9. One such cross, to *i bz wx,* was particularly instructive. The locus of *bz* (bronze, very light aleurone color) lies between those of *I* and *Wx*. The *Wx* locus is closest to the centromere, but the loci of *Wd, I, Bz,* and *Wx* are all included in the distal two-thirds of the short arm. On examination of the types of kernel resulting from this cross, it was again apparent that some kind of chromatin loss, involving a segment of the short arm of chromosome 9 that included at least the *I, Bz,* and *Wx* loci, was responsible for the variegation patterns observed in some of the resulting kernels. In these crosses, the behavior of chromosome 9 in endosperm development could be critically evaluated, from a genetic point of view, only in those kernels that had received an *I*-carrying chromosome from the white-streaked parent. The aleurone variegation pattern, involving the alleles *I* and *i, Bz* and *bz,* or *Wx* and *wx* in the kernel, and the white-streaked pattern, involving *Wd* and *wd* in the plant, clearly differed from the previously known chromatin-loss patterns associated with ring chromosomes or with the chromosome or chromatid bridge cycles. In all appropriate crosses, an additional fact was noted. Somatic elimination of chromatin was observed mainly in those *I* kernels that had received an *I wx* chromosome—that is, a chromosome 9 resulting from a crossover between the loci of *I* and *Wx* in the white-streaked parent plant. Relatively few *I Wx* chromosomes were undergoing chromatin elimination. This would suggest that if a locus in chromosome 9 is responsible for the somatic elimination of segments of chromatin, its position in the chromosome is proximal but close to the *wx* locus. This would place the chromatin-elimination locus in the *Wd i wx* chromosome of the streaked parent plant. To illustrate the present knowledge of the nature of this chromatin-elimination phenomenon, the subsequent behavior of one *I wx* chromosome will be briefly described.

In the cross of a white-streaked plant with the constitution *wd I Wx/Wd i wx* to a normal plant homozygous for *Wd i wx,* an *I wx* kernel, highly speckled with *i,* was removed and germinated. A normal-appearing, nonstreaked plant arose from this kernel. The plant was self-pollinated. On the resulting ear, there again appeared *I* kernels that were highly spotted with *i.* This time, however, in contrast with the above crosses, a large number of these

kernels were present. The seedlings grown from the kernels of this ear were classified into three distinct types: green seedlings with few or no white streaks, green seedlings highly streaked with white, and totally white seedlings. The proportions of these seedling types arising from the nonspotted or only very moderately spotted *I* kernels, the heavily spotted *I* kernels, and the *i* kernels are given in the accompanying table.

TYPES OF SEEDLINGS ARISING FROM THREE CLASSES OF KERNELS FOLLOWING SELF-POLLINATION OF A WD I/WD I PLANT

CLASS OF KERNELS	NO. OF SEEDLINGS		
	Green	White-streaked	White
I.....	63	5	33
Highly spotted....	21	4	1
i.....	70	1	0

All the 10 highly streaked seedlings, and one obviously peculiar nonstreaked seedling arising from an *i* kernel, were transplanted to the field in the summer of 1946. The white streaks continued to appear in the leaves as the heavily streaked seedlings developed into mature plants. The patterns were similar to those of the original white-streaked plants, but the total number of such fine white streaks was enormously greater. In contrast, the nonstreaked seedling remained nonstreaked throughout its development.

To observe whether chromatin losses could be seen in somatic mitoses of tissues that were relatively late in their developmental period, whole mounts of the young membranous glumes in the florets of the tassels of the streaked plants and the nonstreaked plant were stained and examined. In all examined glumes, many cells showed, besides their main nucleus, a very small micronucleus or a very small deep-staining pycnotic chromatin body. The majority of the anaphase figures appeared normal, but in some late anaphases one fragment or two identical-sized fragments were observed. Time did not allow a detailed study of the sequence of events or of the frequencies or types of fragment formation. An examination of the sporocytes of the anthers of all 11 plants, however, has thrown some light on the nature of the fragmentation phenomenon.

The chromosome-9 constitution at pachytene in the microsporocytes of all 11 plants was examined. In all 10 white-streaked plants, many of the sporocytes showed the presence of a morphologically normal chromosome 9 and a chromosome 9 carrying the minute *wd*-producing deficiency. In the nonstreaked plant, two morphologically normal chromosomes 9 were present in many of the sporocytes; the *wd*-producing deficiency was not present in this plant. In the individual anthers of all 11 plants, however, the sporocytes exhibited mosaicism for a deficiency of a long segment of the short arm of chromosome 9. In many sporocytes, loss of the segment from one chromosome 9 had occurred in a recent premeiotic mitosis, although in some cases losses had occurred earlier to give rise to a relatively large cluster of related sporocytes each having a long deficiency in one chromosome 9. In a number of sporocytes, a small deep-staining pycnotic chromatin body was present in the cytoplasm. In many of these cells, in turn, the constitution of the chromosome-9 bivalent could be analyzed. In the clearest cases, it could be determined with certainty that one chromosome 9 was deficient for a large segment of the short arm. Thus, a correlation could be obtained between the presence of the pycnotic chromatin body in the cytoplasm of a cell and the absence of a long segment from the short arm of

one chromosome 9 of the same cell. The cytological studies must be greatly extended in order to clarify and complete the needed information, but it is quite clear that the positions of "breakage" in chromosome 9 do not occur at random. In a large number of figures, it could be determined that the segment deleted from the nucleus at an anaphase included the terminal two-thirds of the short arm; in other words, the break, in each case, occurred at a position approximately one-third the distance from the centromere. The acentric segment that resulted from such a break was subsequently lost to the nuclei during a mitosis. Not all were immediately lost, however, for in some sporocytes a bivalent acentric terminal segment of chromosome 9 was present along with the normal and deficient chromosomes 9. Various types of synaptic association were observed between the acentric segments and the short arm of the unbroken chromosome 9. In a number of sporocytes, what appeared, on rapid examination, to be a normally synapsed bivalent chromosome 9 proved to be otherwise. In the short arm of one of the chromosomes of the bivalent, a break was unquestionably present at a position approximately one-third the distance from the centromere. Very occasionally, cells were observed with other abnormalities of chromosome 9. It is possible that these resulted from secondary effects of the primary breakage process, but any conclusions must await a more extensive study. The nature of the process that is responsible for this most unusual type of chromosome "breakage" is not understood. Two lines of evidence indicate that the locus of breakage is not a "weak" spot in the chromosome that is subject to breakage following unusual tension on the chromosome. If a chromosome with this locus is subjected to the chromatin bridge cycles, breaks occur at various positions in the short arm regardless of this locus. Furthermore, the presence of distinct sectors, each one with its own uniform rate of breakage of the chromosome at this locus, cannot readily be interpreted on the basis of a structurally weak spot in the chromosome. It may be suspected that the "breakage" occurs during the chromosome reduplication process as a consequence of some yet-undetermined abnormality that is present at this one particular locus in the chromosome. Such a modified locus should be subject to genetic analyses. Preliminary genetic evidence derived from plants that were heterozygous for various mutants in the short arm of chromosome 9, as well as heterozygous for this altered locus, have placed this locus in a position which conforms to the position that had been determined cytologically.

It should be mentioned that the single non-white-streaked plant was unusual because of the very high rate of breakage that occurred in it. Both chromosomes 9 underwent the breakage phenomenon, but only occasionally did breakage involve both chromosomes 9 in a single nucleus. When this occurred in a meiotic nucleus, it produced unquestionable evidence for the precise localization of the breaks in chromosome 9. A genotypically complete chromosome-9 bivalent was present at pachytene, but in the form of two entirely detached segments. The homologously associated distal two-thirds of the short arms of both chromosomes 9 formed one segment; the other segment was composed of the homologously associated long arms, the centromeres, and the proximal third of the short arms. It could readily be observed that the break had occurred at the very same locus in each chromosome 9. This was the same locus of breakage that had been observed when only one of the two chromosomes 9 had been broken. It is

possible that in this plant the excessive rate of loss from somatic nuclei of the large segment of chromosome 9 was responsible for its selection as an aberrant seedling. The leaf tissue of the seedling probably was heavily mosaic for different genomic complements of chromosome 9. This may have been responsible for its atypical appearance.

The cytological observations of breakage of chromosomes 9, predominantly at a particular locus, and of the subsequent elimination of the acentric segment that results, are consistent with the genetic observations. This segment carries the loci of *Wd, I, Bz,* and *Wx,* in this order. If, in heterozygous plants, these dominant alleles are carried by the chromosome that is undergoing breakage in various somatic cells, simultaneous losses of these dominant alleles should occur following deletion of the acentric fragment from a nucleus. In the kernels, such simultaneous losses of the *I, Bz,* and *Wx* loci have been observed. It is apparent that the loss of the *Wd* locus accounts for the white (*wd*) streaks in the heterozygous plants.

Although the factors responsible for this breakage phenomenon are not understood, nevertheless the factors that control the frequency and the timing of such occurrences are similar to those that control the frequency and timing of dominantly directed mutations in the variegation types previously described. In the case of the chromosome-breakage variegation just described, however, the breakage itself corresponds to the "gene" mutations observed in the other variegations. Possibly the resemblance is more than coincidental, in that the underlying phenomena are basically similar.

COTTON GENETICS

S. G. Stephens and B. J. Cassidy

Interspecific Relationships

The majority of *Gossypium* species fall into three well marked cytological groups: an A group, consisting of the cultivated diploid cottons and confined to the Old World; a D group of wild diploids confined to the Pacific coasts of the American continents and their adjacent islands; and an AD (amphidiploid) cultivated group which is widely distributed throughout subtropical regions but which has centers of maximum variability located in the New World. Species within the A group are interfertile and have been subjected to comparative genetic analysis. To a lesser degree the species within the D group are also interfertile, but for technical reasons their comparative genetics has been but poorly studied. The AD species are interfertile and have been studied extensively. Recently it has been found that colchicine-synthesized amphidiploids, *G. arboreum* (A) × *G. thurberi* (D), are interfertile with naturally occurring AD species. It is clear, therefore, that *Gossypium* furnishes excellent material for a study of the comparative genetics and evolution of a whole genus.

The first step required in a comprehensive program is the synthesis of all possible AD types from existing A and D species. Theoretically it should be possible to synthesize, by hybridization and colchicine treatment, ten to twelve distinct AD types, all of which should be to some extent interfertile with naturally occurring AD amphidiploids. In practice, this possibility is severely limited at the outset by the fact that most of the hybrids, A × D, are exceedingly difficult to obtain. In performing the cross, fertilization is usually effected, and a fairly complete set of "seeds" is

obtained. The capsules enlarge, and persist for full term; and at maturity small, but superficially normal, linted "seeds" are obtained. Almost invariably, however, these "seeds" are devoid of any embryo, or, more rarely, produce weak seedlings, which cease development in the cotyledon stage. There is good reason to believe that this inviability is not zygotic, but due to incompatibility between embryo, endosperm, and maternal tissues, because autotetraploid (AA) types when crossed with D species usually produce vigorous triploid hybrid offspring. An investigation was therefore undertaken to determine at what stage the hybrid embryos die and to explore the possibility of culturing them *in vitro* before this critical stage.

The types chosen for study were two strains of *G. arboreum* (A group) and a single stock of *G. klotzschianum* var. *davidsonii* (D group). Viable hybrids have never been recorded from crosses between these species. Under greenhouse conditions here a period of 9 to 10 weeks elapsed between fertilization and seed maturity in all three types (about 50 per cent longer than is usual when they are grown in their natural habitats). In selfed seeds of all three types, 3 weeks after fertilization, the differentiation of the embryo into radicle and cotyledons could be first distinguished under low power of a dissecting microscope; and this was the earliest stage at which it was found technically practicable to remove the embryo from the maternal tissues without undue damage. Subsequently the endosperm developed rapidly; and at 4 weeks the embryo, with flattened, closely adpressed cotyledons, was completely embedded in it. At 5 weeks the cotyledons had curved round inside the seed coat, enfolding the upper half of the endosperm. At 6 weeks the endosperm was completely enclosed by the cotyledons. During the last 4 weeks the endosperm was rapidly absorbed, and the cotyledons became fleshy and the seed coat tough and leathery.

The maturation of the hybrid seed, *G. arboreum* × *G. davidsonii,* presented a very different picture. The initial development of the embryo was much slower than in the parental strains. After 3 weeks a considerable increase in size of the seed had taken place, but no clear differentiation of the embryo could be distinguished under the dissecting microscope. At 4 weeks the majority of the seeds had enormously thickened seed coats, endosperm was lacking, and the embryo could be distinguished as a brown, disintegrating mass at one end of the seed. Development of the embryo had usually not reached the "3-week stage" of the parental strains. In a low proportion of the hybrid seeds, a small endosperm developed. In such cases the embryo developed slowly and in 6 weeks reached a stage roughly corresponding to the 4-week stage in the parental strains, but by this time the endosperm was always completely absorbed, and the embryo subsequently dried out without further development. It seems likely, therefore, that the immediate cause of inviability of the hybrid embryo is starvation, due either to complete failure or, less frequently, to inadequate development of the endosperm. Any *in vitro* cultural technique, to be successful, would have to be capable of growing young embryos at the stage corresponding to the "4-week" stage in the parental strains—i.e., when the cotyledons are just beginning to enclose the upper part of the endosperm.

Attempts to culture immature embryos have so far proved very unpromising. Embryos from selfed seeds of *G. arboreum* (A group) and *G. barbadense* (AD group) at the 6-week stage can be rather easily grown on the inorganic components of either White's or Robbins' medium; but

no further development has been induced in younger embryos on culturing in complete media (inorganics + sucrose + nutrilites) or in media supplemented with yeast, malt extracts, or coconut milk. Variations in pH, concentration, temperature, or methods of sterilizing media proved ineffective. Neither were differences in growth observed when embryos enclosed in their endosperms were compared with embryos from which the endosperms had been removed. It seems possible that a physical rather than a chemical limiting factor is involved, since embryos at the 6-week stage or older grew more rapidly on liquid than on agar media.

Partially fertile allotetraploids have been synthesized by colchicine treatment from hybrids between the A-group species *G. arboreum* and *G. herbaceum* and two wild Old World species, *G. anomalum* (Africa) and *G. stocksii* (Indo-Arabia). These allotetraploids are now being intercrossed to explore the possibility of studying the comparative genetics of the *anomalum* and *stocksii* genomes.

Pseudoallelism

Chemical studies of the anthocyanin "alleles" in Asiatic cottons. In Asiatic (A-group) cottons, the distribution of anthocyanin pigment in the petals and vegetative parts of the plant is controlled by a single "allelic" system, of which twenty members have already been described. Their heterozygotes exhibit mosaic dominance, similar to that described by Tan (1946) in *Harmonia*. Recently Yu and Chang (in press) have brought forward genetic evidence that the formerly supposed "allelic" series is really a complex involving a minimum of three closely linked loci, which can be separated or recombined by rare crossovers to give new "mutant" forms. Their data not only provide a satisfactory explanation of the large number of "alleles" that have been distinguished, and of the mosaic dominance shown by their heterozygotes, but also throw light on an interesting complementary interaction exhibited by two members of the series and first described by Hutchinson (1932). The alleles involved produce the following phenotypes: (1) Red Spot—yellow petal with red spot at the base; (2) Ghost—yellow petal with white spot at the base; (3) Spotless—yellow petal, no spot; (4) Basic Spotless—phenotypically indistinguishable from (3). The yellow color of the petal is produced by a gene, *Y*, independent of the anthocyanin genes under discussion, and present in all four types.

Red Spot is completely dominant over the other three types, and Basic Spotless is the basic recessive of the series. When Ghost is crossed with Spotless the hybrid obtained is phenotypically indistinguishable from Red Spot, but segregates 1 Ghost : 2 Red Spot : 1 Spotless on selfing. From Yu and Chang's evidence it appears that two genes must be present at adjacent loci to produce Red Spot. Ghost types lack one gene, Spotless types the other; and in Basic Spotless both genes are absent. A question of fundamental importance is whether the two loci originated by duplication of a single locus, or whether they represent genetically independent loci, which owe their adjacent positions to chance or natural selection. If the former should be the correct interpretation, it would suggest that duplication had been accompanied by gene differentiation (otherwise the Ghost × Spotless complementary interaction would not be expected), and, further, would provide a possible mechanism by which mutual masking of mutants at duplicate loci might be avoided. Such a mechanism might be of considerable evolutionary significance, providing a means by which polyploids, in which initially many genes

must be duplicated, could regain a functional diploid condition.

To investigate this point further, a comparative chemical study of the pigments in the four flower types concerned was undertaken, and an attempt made to discover what processes are controlled by the adjacent loci. Close similarity in the respective gene-controlled processes would suggest a degree of homology compatible with a theory of origin by duplication. The results, which will be published in detail elsewhere, seem to justify the following conclusions:

1. Ghost-type petals, which contain no anthocyanin pigment, accumulate considerable amounts of a leuco substance readily convertible to anthocyanin *in vitro* by boiling with hydrochloric acid. This substance is chiefly located in the spot area of the petal. The conversion of the leuco substance to anthocyanin, in acid solution, is reversible when mild oxidizing agents such as methylene blue or potassium ferricyanide are added to the system. It may be concluded that the anthocyanin is a reduced form of the leuco precursor.

2. Petals in developing flower buds of all four types contain appreciable quantities of the leuco substance. Two days before flowering this substance is rapidly removed in the Spotless and Basic Spotless types, while its content is maintained in Ghost. In Red Spot it is presumably converted into anthocyanin.

3. The fact that the Ghost type accumulates the leuco substance, which it is unable to convert into anthocyanin, together with the fact that Ghost × Spotless hybrids produce a red spot, clearly suggests that the Spotless type carries a gene that controls (presumably through a specific enzyme system) the reduction of the leuco substance to anthocyanin.

4. Aqueous extracts of the leuco substance are unstable on boiling, or on warming with dilute hydrogen peroxide. Small quantities of a yellow substance, with properties resembling those of the naturally occurring yellow (anthoxanthin) pigments of the petal, are produced. It seems likely that the leuco substance is a common precursor from which anthoxanthin (by oxidation) and anthocyanin (by reduction) are produced in the plant.

5. Chemical studies of the pigment extracts from developing petals, and a preliminary microscopic examination of pigment distribution in the living petals at successive stages, agree with the following —at present tentative—interpretation. The leuco substance is first produced in the petal and progressively converted into anthoxanthin. This process is carried almost to completion in Spotless and Basic Spotless types. In Ghost, white strips appear on the inner surface at the base of the petal and eventually coalesce to form a white spot. In Red Spot, similar white strips appear, but in addition patches of cells at the middle of each strip develop anthocyanin, the colored areas subsequently extending and keeping pace with the increasing white areas until finally a homogeneous red spot is produced. The gene carried by Ghost can apparently reconvert (reduce) anthoxanthin to leuco substance in the spot area, thus maintaining the leuco content of the petal; the gene carried by Spotless can, when combined with Ghost, reduce the leuco substance accumulated by the latter to anthocyanin. If further work substantiates this interpretation, it would appear that the adjacent genes control similar (reduction) reactions but act on specifically distinct, though structurally closely related, substrates (anthoxanthin and leuco substance). This similarity suggests a common origin (by duplication), which has been accompanied or succeeded by the development of specificity in substrate requirement.

Possible pseudoallelism in the Crinkle-Contorta series. A second supposedly allelic series in *Gossypium* occurs in the amphidiploid group (AD). It includes five members, of which three—Normal (*Cr*), Crinkle (cr^D), and Contorta (cr^C)—are of interest here. The Normal plant has normal growth with no dwarfing or leaf abnormality. Crinkle produces a dwarf plant with reduced lateral branching, and leaves with veins so shortened that the intervenous tissue is forced into puckers or crinkles between them. In Contorta the plant is dwarfed, the petioles are lengthened, and the leaf blades are reduced to such an extent that the leaves consist of little more than flattened bundles of closely adpressed veins. To some extent Crinkle and Contorta may be regarded as reciprocal leaf abnormalities, since in the former the ratio of vein growth to mesophyll growth is smaller than in Normal plants, whereas in the latter this ratio is greater than in Normal. Crinkle is completely recessive to Normal, Contorta only partially so; the hybrid Contorta × Crinkle is phenotypically Normal. This striking complementary interaction, in view of the rather similar situation in the anthocyanin series described above, suggests that two linked loci rather than a single locus may be involved. There is not yet, however, any genetic evidence in support of this. An alternative possibility—that the Contorta and Crinkle mutants represent, respectively, plus and minus deviations from Normal, which cancel each other in their hybrid—is unlikely for two reasons. First, it is known that changes in the residual genotype that diminish the effect of Crinkle fail to modify the expression of Contorta. Second, close phenocopies of Contorta can be produced by treating the growing points of Normal plants with the synthetic growth substance β-naphthoxyacetic acid. But when growing points of Crinkle plants are treated with identical doses of the same growth substance, "Contorta-like" effects are superimposed on the Crinkle phenotype; that is, the latter is not normalized as might be expected if Crinkle and Contorta represented opposite deviations from the norm.

It may be that the Crinkle-Contorta series involves duplicate loci, both of which are concerned with the synthesis of indole in the plant. The considerable work that has been carried out by plant physiologists and biochemists has shown that many synthetic growth substances have a similar chemical structure, and that certain of them, in addition to their growth-promoting activity, produce marked morphological abnormalities (e.g., naphthoxy- and phenoxy- compounds). Others, which are structurally related but have little growth activity, can successfully compete with and block the effect of active growth substances, thus acting as auxin poisons (e.g., phenyl butyric acid). The working hypothesis that the Contorta and Crinkle mutants fail to produce indole, but are able to synthesize structurally related substances, one causing leaf abnormalities and the other acting as an auxin poison, is now being tested.

SOME PROBLEMS IN NUCLEAR PHYSICS

U. Fano

Dr. Fano was in residence in New York from December 10, 1945 to June 22, 1946, and in Cold Spring Harbor from June 22 to September 7, 1946. During this period he carried out theoretical research work at the Pupin Physics Laboratory at Columbia University and at the Department of Genetics.

The work at the Department of Genetics included a contribution to the interpretation of Dr. Kaufmann's data on chromosomal rearrangements in *Drosophila* (see pp. 158–159). It was also concerned with the further development of other projects, particularly on mathematical statistics, which had been begun in previous years and are not yet completed.

The work at the Pupin Laboratory dealt primarily with the following theoretical problems, which are of particular interest for the nuclear physics program being carried out in that laboratory.

Electric Quadrupole Coupling of the Nuclear Spin with the Rotation of a Polar Diatomic Molecule in an External Electric Field

The rotational spectrum of a polar molecule in an electric field may have a hyperfine structure, owing to various interactions between the nuclei and the rest of the molecule. The electric quadrupole interaction between the nuclei and the rest of the molecule, if present, is likely to be the major factor in this connection. Experimental investigation of this hyperfine structure may therefore yield basic information on the charge distribution within the nuclei, provided that the necessary theoretical tools are available. To provide these tools, Fano has given formulas which serve to determine the hyperfine spectrum of a rotating molecule in various cases, depending on the quadrupole moment of each nucleus, on the external-field strength, and on the rotational quantum number. He carried out a complete calculation for a case in which only one of the nuclei has a quadrupole moment, the molecule is in a rotational state (1; ± 1 or 0), and the interaction between the field and the molecular dipole is comparable with that between the dipole and the nuclear spin.

Electron-Proton Interaction and the Hyperfine Spectrum of the Hydrogen Atom

The energy difference between the two forms of the ground state of the hydrogen atom, in which the spins of the electron and of the proton have parallel or antiparallel orientations, is now accessible to accurate measurement. Such measurement will yield fundamental information on the interaction between the proton and the electron. To make the best use of such information it may be necessary to develop the theory of a system consisting of these two elementary particles to a higher degree of approximation than has previously been achieved. Fano has been re-examining this problem.

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DIVISION OF HISTORICAL RESEARCH

Cambridge, Massachusetts

A. V. KIDDER, *Chairman*

With the return of all but one of the members of the staff who were in the armed forces or other government service during the war, it has been possible to resume normal research activities. "Reconversion" could not be rapid, however, for in each instance work had been abruptly interrupted and the individuals concerned were intensely preoccupied for years with matters so far removed from their former interests that there has of necessity been a period of reorientation and review, both of their own materials and of data that accrued during their absence. Furthermore, the almost entire halting of field investigations and, in the case of those in service, the impossibility of completing reports have thrown the Division program badly off schedule.

As has been stated in previous Year Books, it was planned that by the late 1940's all projects should be brought to a stage at which results could be summarized, conclusions drawn, problems formulated, and recommendations for future research be presented to the President and Trustees. This will still be done, but, as certain undertakings will have to be curtailed and others abandoned, it has become evident that immediate plans and long-range objectives must be restudied. For this reason, and also because the war hiatus and changing conditions in the postwar world make such a review singularly opportune, the members of the archaeological staff will hold a conference in Cambridge in September.

One of the most important matters for consideration at the conference will be that of recommendations to be made to the Institution regarding the nature and the locus of archaeological activity after the current series of investigations has been completed. Until now the major effort of the Division has been confined to the area occupied by Maya-speaking peoples, the archaeological work being keyed with studies of linguistics, ethnology, documentary history, and environmental conditions, in an attempt to follow the career of the Maya from the earliest times to the present. It has become evident, however, that hereafter it will be necessary to confine attention to the prehistoric period. This alters the situation to the extent that, if it seems desirable, the field of work can be broadened.

The problem of whether or not it will be best to continue intensive research on the preconquest Maya is a difficult one. The Maya were artistically and intellectually the foremost group of pre-Columbian Americans. Knowledge of the origin, spread, and decline of their remarkable culture—knowledge which, it might be hoped, would bring understanding of what caused its efflorescence and what led to its ultimate withering—would constitute a very great contribution to the biology, so to speak, of civilization itself. Carnegie Institution has specialized on the Maya for over thirty years: most of the members of its archaeological staff are authorities on one aspect or another of Maya research; the Institution's work has reached a point at which each new bit of information is of cumulative value. On the other hand, what the Institution and others have done

has made it clear that the Maya were not, as was once supposed, uniquely outstanding as leaders in development of higher aboriginal culture. It is true that they were in many ways its most brilliant exponents, but it is now realized that, like the Greeks, they built on foundations reared by earlier peoples and that they were but one of many groups in both North and South America all of which played parts of greater or less importance on the New World stage. Yet our knowledge of this great human drama is very uneven. As to what took place in certain areas—southwestern United States, the Valley of Mexico, parts of the Andean region—we have a great deal of information; as to others, possibly no less important and without question of much significance in the total picture, we know next to nothing. It might therefore be argued that the Institution should set itself the task of filling some of the most obvious gaps.

Decision on this fundamental question involves consideration of the interests and the special abilities of various staff members, of facilities for work in other areas, and of the plans of other private and governmental agencies. No matter how it is resolved, certain investigations now in progress should, of course, be brought to the already mentioned stage of summary and interim report. On some of these, considerable progress was made during the past season. One or two are here briefly described; fuller statements regarding these and others appear in the body of this report.

A. L. Smith carried forward the reconnaissance survey of ruins in the Guatemala highlands. This project, inaugurated in 1945, is designed as a preliminary "stock-taking" of ancient sites in a hitherto very little known area which was heavily occupied over a long period in prehistoric times and which lies athwart one of the principal north-south routes of aboriginal migration and trade. It also occupies a position between the fertile and formerly even more densely inhabited Pacific slope and the valleys leading downward to the lowlands of Peten, where Maya culture achieved its highest development. Particular attention is being paid to the chronological relations of fortified hilltop and undefended valley sites. It is hoped eventually to excavate intensively at one of each type. In the period under review, work was confined to the Department of Quiche, most of the four months available having been spent in the Nebaj area.

At Nebaj was made one of those unforeseen discoveries which so often upset the advance plans for archaeological field work. Mr. Smith aimed to locate ruins over an extensive area and to obtain descriptions and photographs of them. Excavation was to be limited to a few pits for the recovery of potsherd samples. He expected, this year, to cover northern Quiche and perhaps the whole of Baja Verapaz. All went according to schedule until he reached Nebaj. There, at a large site, he found a funnel-shaped depression in the frontal platform of one of the principal mounds. Guessing correctly that this must have been caused by the collapse of a vaulted tomb and believing that it must lie close below, he obtained permission from the landowner, engaged diggers, and started hopefully down. To make a very long story short, the tomb proved to be no less than 30 feet down. To reach its floor, clear and remove its rich contents, and pack for hauling over mountain roads to the laboratory in Guatemala City the scores of specimens recovered, required a full month, by the end of which the rains had begun and further exploration became impossible. But the dislocation of the timetable was amply justified, for the tomb yielded some forty-five specimens of pot-

tery representing a very little known period, and one of the most beautiful collections of jade ornaments that has yet come to light.

Mr. Ruppert spent two months in Yucatan on what might be called a "cleanup" job, made necessary by certain gaps in the Division's published record of its many years' work at Chichen Itza. The principal undertakings at that great site, such as the excavation and repair of the Temple of the Warriors, the Caracol, the Mercado, and the Temple of the Wall Panels, have been reported upon; a manuscript on the Monjas awaits the press. But a number of smaller buildings that were wholly or partly excavated have not yet been described. There are still others, unexcavated but in sufficiently good preservation to yield valuable architectural information. On return from his overseas duty in the American Field Service, Mr. Ruppert devoted himself to checking the notes taken by himself and others on the cleared but unpublished structures, and his own notes on structures at which no digging had been done. As is always the case, he found that more data and additional photographs were needed to enable him to prepare an adequate report. During the past winter these materials were gathered and the nature of several hitherto unidentified ruins was determined.

Gustav Strömsvik, having received his discharge from the Norwegian Navy, resumed his work at Copan. The decade of his activities there has worked wonders in the development of that in many ways most remarkable of all Maya ruins. Its extraordinary monuments have been reerected, several of the most important buildings repaired, the great hieroglyphic stairway restored to its full height. The Copan River, which was steadily eating its way into the massive acropolis, has been diverted into a new channel. Yet by the wise sparing of many of the noble trees from the tropical forest that once engulfed Copan, by leaving untouched large portions of the wrecked and tumbled masonry of its temples, and by skillful restraint in the repair of those that he excavated, Mr. Strömsvik has made evident the high achievements of the ancient architects and sculptors without destroying the powerful psychological effect of what time and the jungle have wrought. Copan symbolizes both the glory of the Maya and the completeness of their fall.

During the year, Sr. Jesus Nuñez, curator of the museum that houses the specimens recovered in the excavations, has acted as guardian of the ruins. The government of Honduras will see to their preservation in their present state.

Mr. Strömsvik opened the past season by repairing two of the monuments at Quirigua that had been damaged by an earthquake. At Copan he put finishing touches on his work of former years. He plans to maintain headquarters there, and to do reconnaissance in the valleys to the east in order to determine the extent to which Maya culture penetrated in that direction and to study its relations to those with which it came into contact.

Dr. John M. Longyear, of the Peabody Museum of Harvard, who before the war had worked for the Division on the pottery of Copan, returned for six weeks to gather further data from a series of stratigraphic trenches. By courtesy of the Honduranian government, which has cooperated most effectively with Carnegie Institution since the beginning of the project, Dr. Longyear was able to bring a large and valuable series of potsherds to Cambridge for laboratory study. An interesting and probably very important byproduct of his work was the finding in the river bank of a deposit of charcoal and flint and obsidian chips below a layer of sterile

alluvium that in turn underlies the deepest pottery-bearing stratum. As not a single potsherd came to light, it is possible that this may represent a pre-ceramic culture, a thing not hitherto discovered in Central America. Further investigation is called for.

In addition to the field work above noted, several other projects were pursued. Dr. H. E. D. Pollock resumed his study of the great mass of material gathered before the war on the architecture of northern Yucatan. Dr. S. G. Morley and Mr. J. E. S. Thompson continued their research on the Maya hieroglyphs; Miss Tatiana Proskouriakoff, hers on Maya sculpture, with special reference to determination of artistic criteria for the dating of monuments which bear no inscription or whose inscriptions are illegible. Miss Anna O. Shepard has sent to press a monograph on plumbate pottery, a ware widely disseminated throughout Mesoamerica and therefore of much significance for working out the chronological and trade relations of cultures during the period of its manufacture. She has also been occupied with a classification of pottery vessel forms and with a study of symmetry in pottery decoration.

Robert E. Smith, in charge of the Division's Guatemala office, has devoted a large share of his time to cooperating with representatives of the Guatemala government in the organization of the National Institute of Archaeology and History, a body designed to further studies of the republic's rich pre-Columbian and postconquest past, and to administer its native and colonial antiquities. He has also served as Executive Chairman of the committee on the splendid new museum now being readied to contain the state's priceless archaeological collections, many of which are the product of the Division's excavations at Uaxactun, Kaminaljuyu, and other sites in Guatemala. Sr. Antonio Tejeda, a member of the Division staff and likewise of the committee, has prepared dioramas, based on drawings by Miss Proskouriakoff, of a series of outstanding Maya ruins.

Mrs. W. H. Harrison, in addition to her duties as Division editor, has been engaged in compiling a dictionary of archaeological terms. Because of conflicting usages, personal predilections for certain terms, and, in many cases, necessity for further research, this greatly needed standardization of nomenclature is proving a long and difficult task.

The Division Chairman spent the winter in Guatemala working on the pottery of Kaminaljuyu and other highland sites. He visited A. L. Smith's excavations at Nebaj, those of Mr. Strömsvik at Copan, and those of the United Fruit Company at Zaculeu under direction of Messrs. John M. Dimick and Stanley H. Boggs. The Chairman is serving as adviser on the latter project, designed by the Fruit Company to provide for Guatemala an excavated and as far as possible restored ruin which will be more accessible to the people of the country and to tourists than are the lowland sites. Zaculeu, capital of Mam Maya at the time of the conquest, is singularly well fitted for this purpose. Many of its buildings are in a good state of preservation; it is magnificently situated at the foot of the towering Cuchumatanes range, close to the city of Huehuetenango, and easily reached by motor or airplane from other parts of the country.

The only archaeological activity outside the Maya field has been that of Dr. E. H. Morris, who has continued his study of the early cultures of southwestern United States.

Researches in documentary history and ethnology also have gone forward. Dr. Scholes and Mr. Roys have sent to press their monograph on Acalan-Tixchel. Dr. Chamberlain, who during the war was Senior Cultural Attaché at the United

States Embassy in Guatemala, has resumed the writing of histories of Montejo's conquests of Yucatan and Honduras. Dr. Robert Redfield, Dean of the Social Sciences at the University of Chicago, has been prevented by other duties from active participation in the ethnological work of the Division, but he has kept in close touch with that of Dr. Tax and Sr. Villa. Reports on the investigations by the latter two on the modern Maya of the Guatemala highlands and of eastern Chiapas respectively are approaching completion. Sr. Rosales' study of the town of San Pedro on Lake Atitlan, and that of Lic. Antonio Goubaud on food consumption and food habits of the Guatemala Indians and Ladinos, will be published in Spanish by the Guatemala government. Lic. Goubaud has been made Director of the Instituto Indigenista Nacional, an agency set up by the new and very progressive government of Guatemala for research on the social and economic problems of the Indians who form so large a percentage of the republic's population.

Guatemala Highlands Project

A. L. Smith

During the 1945–1946 field season Mr. A. L. Smith, assisted by Sr. Cesar Tejeda and Mr. Douglas Binney, continued the archaeological reconnaissance of the Departments of Huehuetenango and Quiche. Permission to operate was granted by the Minister of Public Education, Dr. Manuel Galich, whose effective cooperation, together with that of the Governor of Quiche and the mayors of the various villages visited, greatly facilitated the recruiting of labor. Fourteen sites were investigated and roughly mapped, and individual structures measured and photographed. In several instances circumstances seemed to warrant fairly extensive digging, which at one site revealed a building sequence and at each of two others resulted in discovery of rich tombs.

The first week was spent at Sacapulas working at the near-by fortified hilltop site of Chutix Tiox, investigated and mapped last year. The ruins were thoroughly bushed and cleared for an aerial photograph, and Structure 11 was excavated in hopes of finding a tomb. None was found, but the structure, a small platform supporting the remains of a superstructure, proved to have been added to at least three times. Chutix Tiox dates from the period of the Spanish conquest or very shortly before. Its buildings are in an excellent state of preservation and it lies close to the main highway between Sacapulas and Huehuetenango. A fence has been put up to protect it from cattle, and, to make it more readily accessible, the Governor of Quiche plans to build a road up to it from the highway. It is without doubt one of the most strategically and picturesquely situated ruins in Guatemala.

During the second week, Quiche, the capital of the Department, was used as a base of operations. In this region three groups were investigated: Comitancillo, Sac Lac, and Laguna Seca. Comitancillo, a well fortified site, about 34 km. north of Quiche, proved to be the most interesting. The ball court, the most important of its thirteen structures, is in a very good state of preservation, has closed end zones, and still retains traces of red, blue, and yellow paint. Another structure of interest is a small truncated pyramid with stairways on three sides. This building apparently was originally completely painted red. Among the sherds recovered was a good percentage of white-on-red Xolchun pottery, a ware found in many of the fortified conquest-period sites. Sac Lac is a small plaza group situated on a plain about 3 km. southeast of Comitancillo. It is now used as a cemetery. Laguna Seca, another small

plaza group, lies about 2 km. west of the village of Joyabaj.

Nebaj, the third largest town in the Department of Quiche, was chosen as the next base. The original plan was to spend about three weeks here and then move on, but the area proved to be of such interest that the rest of the field season, with the exception of a week at the Brol finca, was spent here. In the immediate vicinity, the ruins of Nebaj, Vitenam, and Tix-chun were studied. The two latter are small, unimportant ball-court groups. The ruins of Nebaj, in the valley just southwest of the town, are quite extensive. The mounds are very large and surround several plazas and courts. In the main plaza there is an alignment of large rough stones whose arrangement may have had astronomical significance. Although one of the largest sites in the Department, Nebaj does not have a ball court. During its investigation a depression was discovered at the base of one of the principal mounds. The possibility that this might have been caused by the caving-in of a tomb made excavation seem worth while. After two weeks of digging, we finally encountered the tomb at a depth of over 9 m. It consisted of a square stone chamber roofed with a corbeled vault, entrance having been gained by means of a stone passageway 5 m. long sealed with a single stone slab. The vault had collapsed, causing the depression above. Besides the human remains, over 40 pottery vessels and some 250 pieces of jade were recovered. The pottery is of the general period represented by that of the late Tzakol and early Tepeu phases at Uaxactun. Before the work was finished at Nebaj, all the stone monuments were whitewashed in readiness for aerial photographs, kindly taken by Colonel Arthur Binney, U. S. Naval Attaché in Guatemala, of the Nebaj mounds, Chutix Tiox, and other ruins.

Still using Nebaj as a base, we visited and mapped several sites near the neighboring villages of Chajul and Cotzal: Huil, Oncap, Mutchil, El Tigre, Acihtz, Pulai, and Vicaveval. Huil lies on the side of a hill about 10 km. north of Chajul. It is a ball-court group consisting of a rectangular plaza with the ball court at one end and structures on the other three sides. A small platform, now used as a shrine by the Indians, stands in the center of the plaza. There are several stucco monuments here in the form of human figures. The ball court has no end zones and, like most of the Huil structures, is very well preserved. The ruins of Oncap are about 6 km. southwest of Chajul. In plan it closely follows Huil, and it is in an equally good state of preservation. Mutchil and El Tigre are two small ball-court groups on Finca Santa Abelina, the property of the Hodgsdon family, some 10 km. northeast of Cotzal. Both sites have open-end ball courts. El Tigre was so named because a stucco jaguar was found in the ruins. Acihtz and Pulai are two small ball-court groups lying in valleys, the former about 4 km. south and the latter 7 km. southwest of Cotzal. The courts have no end zones, and very little masonry appeared at either. The ruins of Vicaveval, a half-hour's walk northwest of Cotzal, are well protected in a depression near the top of a high hill. Its ball court, which has closed end zones, is situated in the center of the depression, three sides of which rise in terraces to a height of over 20 m. and form a regular stadium from which to watch the game. On the opposite side of the hill from Vicaveval and a little higher there is a cave in which were the remains of at least forty skeletons. Twenty-two skulls were still there, but many had been taken away over a period of some years. No pottery was found with the skeletons, which undoubtedly date from before the conquest. A

good deal of burnt wood was scattered among the bones.

The season's work was wound up at the Brol family's Finca San Francisco, some 17 km. northeast of Cotzal. There are two ruins: San Francisco and Tzicuay. The former, in a cane field on the edge of the Rio Chipal 0.5 km. southeast of the Brol residence, was mapped by Robert Burkett some thirty-three years ago. Today there is practically no masonry showing. It is a ball-court group, the court having end zones. Tzicuay, also a ball-court group, is on the tip of a low promontory projecting from the side of a high range of hills, about 1.5 km. west of the Brol residence. The buildings retain considerable masonry. The ball court has well marked end zones; in its east range is a masonry tomb with corbeled vault and short entrance passage. Unfortunately, it had recently been entered and disturbed, but 74 pottery vessels were recovered, most of them unbroken. Although it has as yet been only cursorily examined, the pottery appears to represent a long sequence of phases, from an early one, possibly contemporaneous with the Chicanel ceramic phase of Uaxactun, to a phase containing the relatively late plumbate ware. This and the fact that many skeletal remains were found pushed to the sides of the tomb to make room for later burials indicate that it was in use for many generations.

It was originally planned to investigate the Rabinal area in the Department of Baja Verapaz, but the unexpectedly long time required for the excavation of Nebaj has forced postponement of that part of the reconnaissance until next year.

Copan Project

Gustav Strömsvik

The 1946 activities of the Copan Project were as follows: repair of the earthquake-damaged monuments at the ruins of Quirigua; study of the causes of the deterioration of the monuments at Quirigua and Copan; continued digging at Copan for recovery of ceramic material; re-erection and repair of the remaining four stelae in the valley of Copan; mapping and reconnaissance digging for ceramic material at the supposed site of Chaves' conquest of the Maya under Copan Calel.

On January 15 repair work started at Quirigua, on Stelae E and J, damaged by the severe earthquake of August 1945, which caused much destruction in the neighborhood. Both E and J had been erected and repaired by the Carnegie Institution in 1934. The violence of the shake having caused considerable chipping around the lines of the old fractures, it was necessary to replace these chips and strengthen the shafts against further damage.

In the case of Stela E, previously broken across the neck of the figure, two steel dowel pins, placed in 1934, had held the top from being thrown off, but had not prevented a slight rocking action that dislodged a number of fairly large flakes on both sides above and below the line of fracture. To prevent a similar occurrence in the future, a 2½-inch hole was drilled lengthwise through the center of the shaft, three ¾-inch reinforcement steel rods, 25 feet long, were threaded down through this, and the remaining space was filled with a mixture of half sand and half ordinary cement. Afterward the flakes that had been thrown off were replaced and held with iron pegs set in holes drilled through the fragments and into the monument. Such cracks as were left were filled with cement and drilling dust of the same rock, a mixture approximating the natural color of the stone.

Stela J, originally broken across the feet of the figure and badly chipped around the break, was repaired in 1934. At that time

a steel rod was placed in a hole longitudinally drilled from top to bottom. This had held the shaft upright but did not prevent some rocking and more chipping during the recent shake. This season it was reinforced by sinking four clamps, spanning the crack, into the four sides of the stela. The clamps were of 1-inch steel, over 1 m. long, with points 0.15–0.20 m. long drilled into the faces of the monument. The chips were replaced in the same manner as on Stela E, and the rods were covered with a similar cement-dust mixture. The present repair should make Stela J at least as strong as it was originally.

During delays in the work on the stela, Zoomorphs M and N were cleaned, repaired, and set on low pedestals. Materials and labor, as well as quarters and board for Mr. Strömsvik, were supplied by the United Fruit Company.

During the more than a decade in which the monuments at Quirigua and Copan have now been under close observation, considerable deterioration has taken place. This is caused by mosses and lichens whose tiny roots penetrate between the particles of the stone and loosen them, apparently by both mechanical and acid action. It is imperative for the future preservation of the monuments to remove these growths and prevent their re-establishing themselves, and to find a hardening agent for the softened surfaces. Obviously the Maya faced the same problem, both at Copan and at Quirigua; their practice, however, of coating monuments with lime plaster and in some cases with red paint must have served to prevent the damage now caused by this type of vegetation.

To fill gaps in existing knowledge of ceramic sequences at Copan, several exploratory trenches were opened south of the Acropolis, after February 10. These were continued and enlarged by Dr. Long-year after his arrival at Copan March 22 (see his report on p. 203).

A resident of Copan, digging for adobe in a small mound at the southern edge of the village, found eight fine large jade plaques, each carved on one side with serpent motifs and a human figure in the classic Copan attitude with hands on breast. At the main ruin there came to light an interesting early drain running toward the river from a long-buried court in the present flying field. This was followed for about 100 m. It was found to have been built in several sections, but had become closed and forgotten during the later centuries of the city's existence.

On recommendation of Dr. Morley, the four remaining fairly complete unrepaired stelae in the Copan valley were re-erected and repaired as far as possible. These are: Stela 10, the West Piedra Pintada; Stela 13, the East Piedra Pintada; Stela 15, lacking its lower third, from Copan village, set up in the museum yard; and Stela 19, in the small valley west of Hacienda Grande, set up in its original position.

Study, cataloguing, and repair were carried out in the Copan Museum, but much more remains to be done.

At the invitation of Mrs. Doris Zemurray Stone, the valley of the Comayagua River was visited during the last week of February. The many Comayagua sites, representing a long period of occupation, merit closer investigation. A very interesting burial cave, newly discovered, was also partly explored. An archaeological museum has been opened in the town of Comayagua; it contains important specimens the study of which will throw much light on the complex problems of Copan and neighboring sites.

The site, mentioned by Fuentes y Guzman in his *Recordación florida,* where Chaves found and fought Copan Calel in the sixteenth century was visited in order

to obtain pottery dating from the early historic period. Sr. Jesus Nuñez, the representative of the government of Honduras at Copan, and Mr. Strömsvik left Copan by air April 22 for Nueva Jocotepeque. Riding up the broad Lempa valley, past the village of Vado Hondo, the party arrived at the village of Santa Anita; here they were shown a fine polychrome "Copador" vase that had been found with a burial in the river bank about 1 km. above the village, where there is a group of rubble mounds on an alluvial plain. In the riverbank were seen sherds of "Copador," bichrome, and monochrome pottery, and fragments of round-bottomed metates and two-faced manos. About four hours' ride up the valley, past Santa Fe, brings one to the settlement of Piñuelas, the last before crossing badlands to the site now called "El Rincon del Jicaque," which is supposed to be the site defended by Copan Calel. It is on an arid mesa in the Comayagua valley, a peninsula almost encircled by the Lempa River, which there flows in a canyon 80–100 m. deep. The narrow neck is closed by a rough stone wall, 2–3 m. high, and could be very easily defended. On the east side an intricate system of toe holds gave access to the river; these were probably used only during sieges. Over fifty house mounds were noted, but excavation would no doubt reveal many more. Only one mound had pyramidal form, about 3 m. high, probably the substructure of a small temple or shrine. The house mounds were rectangles bordered by a base course of rough stones, with tamped gravel and ash floors raised about 20–30 cm. above ground level. The small amount of rubble on the floors suggests that walls were of wattle-and-daub and roofs of thatch. Fragments of unshaped slab metates and short two-faced manos were found. Considerable digging in the scant topsoil yielded very few potsherds, mostly from crudely made water jars. It is obvious that the site was but briefly occupied.

Copan Pottery

John M. Longyear, III

Dr. Longyear spent six weeks at Copan in March and April 1946, gathering ceramic data to supplement the material collected in previous years (Year Books Nos. 37 and 38) and observing the results of excavations conducted at Copan during the past few seasons. Six stratigraphic trenches were dug for pottery specimens, a large portion of the latter being brought to the United States for study. In addition, all vessels excavated since 1939 were photographed and described, and the catalogue of the museum at Copan was brought up to date. At the conclusion of his stay in Copan, Dr. Longyear paid a short visit to San Salvador, to inspect the pottery excavated at Tazumal in 1943–1944 by Mr. Stanley H. Boggs.

A rich burial area, some 200 m. south of the Acropolis, was selected as the site of the principal stratigraphic trench dug at Copan this season. Excavations had been made here in 1942 by Mr. Strömsvik (Year Book No. 41), and deep sherd-bearing deposits found. The new trench, 18 m. long, was excavated in blocks 1 m. square taken down in arbitrary levels 50 cm. in thickness. The other five trenches, to the west and south of the Acropolis, yielded specimens supplementing those recovered from the principal trench.

From field observations the following tentative conclusions may be drawn: The lowest stratum in the trenches consisted of a dense deposit of monochrome and bichrome sherds, intermixed with large quantities of fresh-water snail shells, together with a few handmade figurines of Playa de los Muertos type. Overlying this earliest level, the first polychrome pottery

appeared, strongly characterized by basal-flanged bowls of Peten Tzakol type. In the uppermost, or latest, strata, the polychrome changed to local styles, with occasional specimens of Ulua-Yojoa wares. In the main, this sequence had been worked out in 1938 and 1939, but two of this year's discoveries were of outstanding importance: the association of handmade figurines with the earliest Copan pottery, and the great preponderance of basal-flanged bowls in the early polychrome levels.

Burials found this year conformed to the sequence established by Strömsvik in 1942 (Year Book No. 41); that is, early interments were extended, with monochrome and bichrome pottery offerings, whereas later skeletons, with inlaid teeth, were buried in flexed position, and offerings, where present, included polychrome wares. In addition, two crude secondary burials were uncovered in a rubbish deposit just west of the Acropolis. It is possible that these are associated with the post-Acropolis occupation of Copan.

Shortly before the end of the season, a level representing an early land surface was discovered in an old river cut south of the Acropolis. This level lay below a stratum containing the earliest pottery yet found at the site, and was separated from it by 40 cm. of sterile river clay. About 5 sq. m. of the deposit was uncovered and carefully excavated before the end of the season. Averaging 10 cm. in thickness, it consisted almost entirely of charcoal, flint and obsidian chips, and broken animal bones. Not a single potsherd or other evidence of ceramic industry was recovered. The charcoal appeared to be scattered rather evenly through the deposit, and thus may have resulted from some natural cause, such as a forest fire. Later in the season, however, Messrs. Kidder and Strömsvik excavated further and located some fire-blackened stones, possibly the remnants of a hearth. The most interesting feature of this early level is the flint and obsidian collection, which consists entirely of irregular flakes, no prismatic cores or parallel-sided blades, so common in the pottery levels above, having been found. None of the flakes have been worked into definite tools, but most of them bear secondary use-chipping along one or more edges. In fact, it is possible to distinguish whole groups of crude implements, such as scrapers and points, by the characteristics of these reworked edges. In an area of flood-plain river deposition, we cannot claim great antiquity for this level solely on the basis of the 40-cm. stratum of sterile clay separating it from the pottery-bearing strata above. It is almost impossible to believe, however, that any deposit contemporaneous with the ceramic industry at Copan could accumulate without the presence of a single potsherd or obsidian blade. At present, therefore, this level must be assigned to a pre-pottery stage, and be considered to represent the most primitive culture yet found in this part of Central America.

Dr. Longyear has also been engaged in study of the design motifs of Copan polychrome pottery. His analysis, although still in an early stage, shows that the local painted wares were rigidly stylized, both in decorative motifs and in the shapes of the vessels on which given motifs could be placed. It is now possible to isolate these Copan styles from those of imported wares, and also to identify them whenever they occur in the ceramic context of other sites. The importance of this study was fully realized when the pottery from Tazumal, El Salvador, was examined. Many of the polychrome wares of the latter site resemble Copan vessels so strongly that there can be no doubt they both stemmed from the same artistic tradition. In other re-

spects, however, the two ruins are entirely different. Here, then, is another example of the duality of Maya culture, first emphasized by Thompson. The basic or lay trait of pottery manufacture and design bridges over the more obvious dissimilarities between Copan and Tazumal—dissimilarities caused by Copan's falling under the influence of the classic Maya hierarchic cult, while Tazumal remained unaffected by it. Further studies of this sort will not only greatly enlarge our knowledge of ancient Mesoamerican cultural origins and relations, but will also help divert the field archaeologist from the straight and narrow path of stratigraphic sequences and statistical potsherd analyses—a path from which it would do many archaeologists no harm occasionally to stray.

Investigations at Chichen Itza

K. Ruppert

During the Division's activity at Chichen Itza (1925–1937), numerous structures lying outside the area occupied by the principal groups were examined by Mr. Ruppert when opportunity offered. In reviewing the notes on these and on other buildings, excavated but as yet unpublished, he found it necessary to re-examine some of them and desirable to study the great number of others shown on the map of the Chichen area surveyed by the Institution in 1924, 1929, and 1932.

Mr. Ruppert left New Orleans February 5, 1946, for Merida, Yucatan. A trip was made to the city of Campeche to examine the collections and to photograph stelae in the local museum. Sr. Raul Pavon Abreu, Director of the museum, was of much help in this activity and also made it possible for Mr. Ruppert to visit the ruins of Edzna in his company and that of the Governor of the state, Lic. Lavalle Urbina. Sr. Pavon has successfully accomplished the excavation of the principal temple at Edzna and deserves unqualified praise for the excellent organization of the Campeche Museum.

Returning to Merida, Mr. Ruppert visited Uxmal and then proceeded to Chichen, where he remained until April 8. During his stay he was the guest of Sr. Fernando Barbachano, head of the Mayaland Tours. Sr. Barbachano's invitation was extended in furtherance of the Institution's archaeological activities, a courtesy most deeply appreciated.

Seven weeks were spent at Chichen Itza, and over 130 structures were studied, measured, and photographed. Only minor excavations were possible in the time available and under the agreement with the Mexican government.

There does not seem to have been an organized plan or arrangement of structures for the area as a whole. Buildings face in all directions, the most common being west; seldom does one face south. Connecting some of the groups are ancient ceremonial roadways or sacbes. One, Sacbe No. 7, extends from the Monjas to the Temple of the Four Lintels, tying together the northern and southern parts of the city. On either side of this roadway, but not directly connected with it, are small assemblages of structures. Throughout the area are isolated terraces and platforms supporting buildings that appear to have been independent units.

Platforms vary greatly in size and shape and have from one to four stairways. Some do not support buildings, others support one or more. The former are classed as shrines or dance platforms and are often located in front of a temple-type structure. When a platform supports a single building it rarely has more than one stairway.

Pyramidal substructures are always covered with debris fallen from above. Infrequently is any of the facing exposed.

Occasionally a part of the base of the stairway may still be made out, and seldom is there more than one stairway; the Castillo and the High Priest's Grave are exceptions. Superstructures are found in varying states of ruin. Some are now little more than rubble heaps which give no clue to their former nature.

Colonnades have a general distribution. No new ball courts were encountered. The six courts in the area are confined to a rather small section around the principal groups.

Hitherto, serpent columns have been found associated with only eight buildings. A ninth was added this season. It is a small two-chambered structure (3E5) apparently resting directly on the great northern platform that supports the Castillo, Temple of the Warriors, and other buildings. One of the columns was partly excavated. The serpent head was not found. It was not an integral part of the first drum as, with one other exception, is the case when the column is round. The upward projection of the tail, not recovered, was a separate stone.

Five additional structures of the gallery-patio complex type, best represented by the Mercado but not noted in the report on that building (Carnegie Inst. Wash. Pub. 546, p. 224), were recognized this season. One may not have had a gallery, three have shrine rooms, one has no columns in the patio, and one has a patio with vaulted chambers on two sides. This latter feature is of considerable importance, and it is regretted that the structure was in such collapse that it was impossible to obtain an accurate ground plan. Vault stones were not noted in the gallery of two of the structures. This is a highly specialized type of building, which, however, shows considerable variation in the eleven examples now known at Chichen Itza.

Mr. Ruppert flew to Mexico City April 10. A trip was made to the ruins of Tula in the state of Hidalgo. This site has a number of affinities to Chichen Itza. Of special interest is a structure somewhat similar to those of the gallery-patio complex type. April 25 was spent at Tajin, Veracruz. Owing to an early rainy season, excavations by the Mexican government had been suspended. Mr. Ruppert returned to the United States May 5.

Architectural Survey of Yucatan

H. E. D. Pollock

Dr. Pollock returned to the Division in September 1945, following Army service of somewhat over three years. At the time of his departure in 1942, he was engaged in preparing for publication the results of field trips to Yucatan and Campeche beginning as far back as 1932. A résumé of the field work of the Architectural Survey with references to earlier reports appears in Year Book No. 39, pp. 265–267.

On resumption of work with the Division, it seemed desirable that Dr. Pollock should spend some time in studying the very considerable amount of Middle American archaeological literature published during his absence. Several months were devoted to this pursuit, and the reward is probably to be measured equally in terms of reorientation of the worker and in knowledge gained of the advancement in research.

It has long been felt by Dr. Pollock that the publication of architectural data should rely mainly on illustration rather than text. The preparation of such material, consisting in the present instance of a great number of drawings as well as photographs, is a time-consuming process. A large amount had been prepared prior to his departure; but the hiatus of almost four years made necessary a thorough recheck to discover what details had been omitted, and to re-

fresh the memory in regard to the general content and specific problems of the task in hand. This work is now in progress.

It is not wise to be rigid in establishing the precise form and content of a publication when the raw data are still in process of reduction to final form. Some thought may nevertheless be given to the problem. In the present instance, information that should some time ago have been available to fellow workers has yet to appear. Moreover, the freshness of the research, as expressed in the myriad details the researcher carries in mind but never reduces to paper, has dimmed. The wise course therefore would seem to be to bring forth as promptly as possible a publication presenting mainly the factual aspects of the field work, and not to delay publication by the preparation of elaborate comparative data. It may indeed be advisable to publish the material in successive parts dealing with sub-areas of the region covered by the survey. When this stock of facts that have sat on the shelf so long is made available to all, comparative studies should be commenced—studies that presumably will be furthered not only by the Division but by other interested workers.

Hieroglyphic Research

S. G. Morley

Dr. Morley left Santa Fe for Yucatan October 28, 1945, by way of Mexico City. During his stay in the capital he visited the ruins of Tula, Hidalgo, which the younger Mexican archaeologists have conclusively demonstrated was the Toltec capital of Tula, and not San Juan Teotihuacan as originally held. The architectural evidence shows a far closer connection between Tula and Chichen Itza than between San Juan Teotihuacan and Chichen Itza; indications are that Tula is pretty surely older than the Mexican Period at Chichen Itza, and that San Juan Teotihuacan is older than Tula.

The Hieroglyphic Dictionary was continued, Dr. Morley supervising and correcting the work of the dictionary draftsman, Sr. Isaac Esquiliano, who has been devoting his entire time to this project for the past four years. Most of the more than 460 known introducing glyphs and glyphs G and F of the Initial Series, as well as glyphs E, D, C, and X of the corresponding Supplementary Series, have been drawn, and it is hoped that all examples of the remaining two signs of the Supplementary Series—glyphs B and A—will be completed by the end of 1946, or early in 1947.

Some important discoveries of new epigraphic material by Mr. Giles G. Healey in the little-known region lying southwest of the Usumacinta River in Chiapas, Mexico, should be reported. At a new site, which he named Oxlahuntun, on the pilasters of a Palenque-type temple, he found the remains of an inscription in stucco, recording the Period Ending date 9.13.0.0.0 8 Ahau 8 Uo; and at another new site named Lacanha, near the Rio Lacanha, were found two inscribed stelae, one of which has the distinction of presenting three Initial Series, recording the following dates:

9 .8. 0 . 0. 0	5 Ahau 3 Chen
9 .6. (0).11. 0	8 Ahau (18 Zac)
(9).8.(12).11.(0)	8 (Ahau 3 Kayab)

This condition is presented by only one other monument in the Corpus Inscriptionum Mayarum (Altar 2 at Uxul, northern Peten, Guatemala, discovered by the Carnegie Institution in 1934).

Work on the reconstructed text of the Maya Chronicles by Professor Alfredo Barrera Vasquez and on the English translation of the Maya original by Barrera Vasquez and Dr. Morley has been com-

pleted, and this manuscript is now ready for publication.

Barrera Vasquez first made a translation of the reconstructed Maya text into Spanish, but it was found that for purposes of the English translation, a more faithful rendering of the original Maya could be achieved by completely by-passing the Spanish translation and putting the Maya directly into English. Indeed, it was found that the meaning of the original Maya could be more accurately rendered in English than in Spanish, because of the non-declensional character of the Maya, which is probably closer in construction to English than to Spanish.

Last year Dr. Morley began to collect, classify, and list all known Maya inscriptions on stone, stucco, and wood, and a few engraved on jade, painted on pottery, or painted on the three known pre-Spanish hieroglyphic codices. The purpose of this project was to make a complete checklist of the Corpus Inscriptionum Mayarum; this is now ready for publication.

The manuscript of Dr. Morley's popular book entitled *The ancient Maya* is now in course of publication, the English edition by the Stanford University Press, and the Spanish edition by El Fondo de Cultura Economica of Mexico City.

Dr. Morley's experience in translating the Maya Chronicles in collaboration with Alfredo Barrera Vasquez had convinced him that for accuracy it would be necessary to be in closest contact with the translator of *The ancient Maya.* He was particularly fortunate in obtaining for this the services of the Hon. Adrian Recinos. Mr. Recinos had previously made a distinguished Spanish translation of Dr. Morley's *Guide book to the ruins of Quirigua,* which the Carnegie Institution published in homage to the Sociedad de Geografía e Historia de Guatemala. Mr. Recinos spent the three winter months with Dr. Morley in Merida. The translation was completed and delivered to El Fondo de Cultura Economica early in March. Both editions are promised for early fall delivery.

Dr. Morley returned to his summer headquarters at Santa Fe, New Mexico, on May 24, to devote the summer and fall to reading proof on these two books.

Hieroglyphic Research

J. E. S. Thompson

During the past year Mr. Thompson has been largely engaged in writing the introductory volume to his survey of Maya hieroglyphic writing. This study has necessitated much research on specific problems of glyph formation.

The selection of some 2000 individual glyphs for illustration and the checking of the artist's drawings with photographs have occupied much time but not been mere drudgery. Such work, in combination with general research on the subject, has revealed what may prove to be the closest approach to a key to Maya hieroglyphic writing which we are ever likely to have. The walls of Jericho will not fall at this blast, but the method may in time enable us to undermine the outlying fortifications in strategic locations.

This new attack, which is a development of those discussed in Year Books Nos. 43 and 44, isolates synonyms in the main elements of glyphs and in their affixes. The system has to be used with some caution, for there is a danger of confusing synonyms with near synonyms. For instance, the various so-called ending signs are not true synonyms, but associated terms. Their meanings may be tentatively accepted as "completion of," "count of," "setting in order of," "expiration of," etc. On the other hand, we find a large number of elements which are always interchangeable. They apparently represent the same

ideas and are true synonyms. The large group of symbols which represent water is a case in point, but the problem is not merely a question of identifying components of the group. A water element may often be added to a glyph to help in its identification. Thus, to a deity connected with rain may be added a water symbol as an attribute, more or less as St. Peter is painted or carved with his keys. Water is the precious object. Accordingly a water symbol could be used in that secondary sense.

Another large group of related symbols refer to the earth and the underworld. Maya deities have a disconcerting freedom of movement. Celestial deities make incursions into the realm of the underworld; terrestrial deities ascend to the skies. Symbols of the underworld serve as distinguishing characteristics of the gods of the nether regions, but they may also be attached to celestial gods to indicate a temporary abode underground. Thus, the sun god at night passes through the underworld on his journey from west to east. On such occasions he is decked with the symbols of the abode of the dead.

Clearly, if more symbols can be assigned to the groups already known, and new groups can be recognized, the problem of the glyphs will be much nearer solution.

One result of this work is to reduce the number of elements which can represent distinct ideas or words. This, of course, lessens the possibilities of much diversity in the still undeciphered parts of the texts. On the other hand, nearly eighty different affixes or pairs of affixes occur with a few of the most important main elements. Some of these combinations represent synonyms or near synonyms; but even allowing for synonymous affixes as yet unidentified, there must be a goodly residue with different meanings.

Maya hieroglyph writing cannot be attacked as an isolated problem. Religious beliefs, legends, associations of ideas, language structure, folkways, and related subjects are deeply involved. For a grasp of them, it is necessary to delve deep in the mythology of the Maya and of their cultural coinheritors to the north. The phraseology of modern Maya prayers is also helpful in elucidating these matters. Collaboration with Ralph L. Roys in these and related problems has been highly rewarding.

A Study of Maya Sculpture

T. Proskouriakoff

A study of the development of monumental sculpture in the Maya area was originally undertaken with the object of resolving specific disagreements which had arisen as to the period of erection of monuments whose style was deemed by some observers to be incompatible with the dates inscribed on them. Although the results have not been in all cases decisive, the study has revealed the possibility of a clearer definition of the trends of artistic development in Maya sculpture than has yet been attempted. An exposition of these artistic changes is useful not only as an aid in establishing the chronological relation of monuments having no decipherable dates, but also in throwing light upon other aspects of culture and in revealing contacts between various sites and between the area as a whole and other regions of Mesoamerica.

The greater part of this year was spent in developing a convenient system of stylistic appraisal based on the duration of traits and qualities of design as determined by their known occurrences. A method was devised by which traits of a given monument can be compared with a standard illustrated series, which also shows on a time scale the periods of which the traits

are characteristic. The time distributions of all the traits observed on the monument are then combined in a single graph which indicates the span of time in which the given combination of traits is most likely to occur. This method is not intended to supplant the more discriminating judgment of experts who can sense variations that cannot be clearly defined. It has the advantage, however, of being less dependent on subjective reactions or preconceived theories of aesthetic evolution, and of demanding no specialized training on the part of the investigator who wishes to make an independent evaluation of the style of a given monument. It is hoped that it will bring into closer agreement opinions which are now widely divergent. The chief limitation of the method is that it rests entirely on the known epigraphic series, which is very unevenly distributed through the body of sculptural material. Close determination of stylistic affiliation, therefore, is possible only for stelae of the period of Initial Series and sculptures of similar type. When this method is tested against the epigraphic series by assigning to each of the 137 dated monuments an optimum date on the basis of its trait graph, the errors resulting are not greater than 2 katuns in about eight out of ten determinations, and not more than 3 katuns in nine out of ten. Larger errors occur when the monument tested is of the early period, which, though of long duration, is scantily represented; when the carving is badly effaced; and sometimes when the design is atypical or poorly executed. In view of the differences in skill and taste of contemporary artists, the unequal distribution of dated material, and the erosion that mars most of the monuments, greater reliability of chronological estimate is perhaps not to be expected.

The illustrated series of traits, chronologically arranged, reveals that the important directions of change are related to purely aesthetic considerations. The traits which show most consistently progressive changes during the period of the Initial Series are those which may be defined as types of form configuration, and not those which are based on the choice of motif. The development, therefore, is most clearly demonstrated by a comparison of abstract decorative forms of similar structure. There appear to be two major periods, separated by a gap of nearly a century (9.4.10.0.0–9.8.15.0.0), which was singularly unproductive of any major sculptural work. The earlier period is too poorly represented to show trends of development, but as a whole may be characterized by distinctive positions of the human figure and by simple structure and configuration of decorative forms, frequently designed with stress on a vertical axis. For the later period, a definite progress can be traced in the study of forms and in their manipulation to produce aesthetic effects. The first sculptures of this period can be recognized by the survival of specific qualities of early arrangements combined with a more studied, but still simple, delineation. The direction of progress is toward more perfect geometric regularity and more complex structure, in which previously independent elements are adapted and related to each other in arrangements which, though not directly copied from nature, resemble natural motifs in their logical organization. Curvilinear rather than axial arrangements predominate in this period, and rhythmic variations of curve and straight line are mathematically precise, as in the progressively diminishing undulations of waving forms, which in the earlier periods tend to be irregular. The latest phase of this development shows emphasis on expressive and mobile qualities of forms and their free adaptation to the purposes of the general composition.

This results in irregularities due to deliberate distortion and exaggeration and culminates in a type of delineation that may be designated as cursive.

In Yucatan the aesthetic development is less consistent, and since there is little material which can be dated on the basis of inscriptions, the definition of trends and influences is more difficult. It is doubtful whether a chronological sequence of monuments in Yucatan can be constructed on the basis of style alone, since many variations, particularly of the later periods, appear to be fusions of different styles, and are dependent on historical juxtaposition of these styles. There is no reason to suppose that they would form in any sense a progressive series. Rare and scattered examples of sculpture closely analogous to that of the earlier phases of development in the south indicate that the progress may have been at first roughly parallel, but the fact that the latest phases cannot be identified in the north may mean that the influx of foreign influences in this area came before the end of the period covered by the Initial Series. The investigation at present is chiefly concerned with defining the qualities of the many schools of Yucatan sculpture and formulating the problems of their interrelation.

The Mexican school of Chichen Itza, which was the last highly developed school in Yucatan, presents interesting opportunities for the study of an eclectic style. It is less preoccupied with the aesthetic effects of form than is the art of the southern area, and concerns itself primarily with the presentation of dramatic subjects, a quality which reflects the troubled spirit of the times. Some of the qualities and even the specific forms it employs are remarkably similar to those of the earliest Maya stelae. Possibly this can be explained by the survival of these traits outside the Maya area and their reintroduction in late times. Similar qualities may be observed in some sculptures of the Puuc, and in very late monuments of the southern area. At Chichen Itza, these apparently archaic traits are combined with others which are directly traceable to the style of Tula, Hidalgo, and still others which appear to stem directly from the tenth-cycle period of the Initial Series. The latter traits, which have not yet been observed in the Puuc, suggest that a fusion of the Tula style with the local variant of the Puuc found at Chichen Itza may not be sufficient in itself to account for the origin of late Chichen Itza sculpture, though no explanation for the presence of these traits is yet apparent.

The problem of the interrelation of styles in Yucatan is very intricate, and a survey of monumental sculpture in this area must rest content with mere suggestions, for the amount of material available for study is relatively meager. The history of design as a whole, however, is probably closely paralleled in architectural ornament, in mural painting, and in pottery decoration and other minor arts. Each of these must contain developments peculiar to its own technique and subject; but they are at all times interrelated, and only detailed descriptive presentations and analytical studies of each of them will make possible a comprehensive study of the progress of artistic styles.

Ceramic Technology

Anna O. Shepard

The temporary cessation of archaeological field work during the war afforded opportunity for investigations which were departures from those previously conducted under the Ceramic Technology Project. Two principal studies under this extended program, that of plumbate, an important Mesoamerican ware, and that of

symmetry in abstract design, were completed in the current year. The advantages of broadening the scope of the project are apparent in view of the extreme specialization which archaeological ceramic technology represents. During the period of establishment of the project, the accumulation of material and the necessity of testing the applicability of many analytical methods restricted Miss Shepard's activities to the purely technical aspects of ceramic research. There was then a large backlog of pottery from earlier excavations, and collections continued to come in from season to season. Extensive analyses were required in order to ascertain the range of materials and techniques used by the Maya and to gauge their possible significance in comparative studies; also the archaeologists reporting on pottery needed data to aid in their classifications. By the end of 1942, systematic and detailed analyses had been made of the more important collections and preliminary study of the others had been completed, many thousands of sherds having been examined microscopically and a variety of techniques identified by chemical and thermal tests. Although only a small part of the data thus amassed has so far been published, they have been made available to five archaeologists working on pottery under the auspices of the Division.

The disadvantages of extreme specialization were frequently apparent during this initial period, especially in attempting to correlate technical and stylistic features. Consequently, when the war stopped the flow of material from excavations, it seemed advisable to choose an archaeologically important ware and study all its aspects, since in this way the leads suggested by relations of composition and style could be followed by means of additional tests and experiments. Plumbate ware was selected for this purpose because its wide distribution through trade makes it particularly useful in relating occupations, and also because it presents interesting problems of origin and development. The study was a long-term one, having been initiated with the analysis of sherds submitted at intervals by various archaeologists and later extended by the examination of large museum and private collections. Reports on the work have appeared in previous Year Books. One recent result brought out in the final revision of the manuscript may be mentioned as typical of the usefulness of mutually supporting data on composition and style. The variety of plumbate represented by sherds from Kaminaljuyu and El Baul is distinguished not only by vessel shape, but also by a consistent difference in paste. Archaeological evidence indicates that this variety antedates the better-known and widely traded variety. With two independent criteria for identification, the significance of hitherto puzzling specimens from Tajumulco in the far western highlands, as well as that of certain outstanding specimens from older collections, could be postulated with confidence. These data give a new frame of reference for the long-standing question of the place of origin of the ware.

The stylistic work on plumbate led to a general review of pottery form and of certain aspects of design. In the search for fundamental properties of abstract design, symmetry was chosen for more intensive study. To the mineralogist, it affords a natural approach because the principles used to describe the form of a crystal are equally applicable in defining the arrangement of regularly repeated parts in a motif, a band, or an all-over pattern. Although several mathematicians have illustrated this fact, their method has been overlooked by students of art, and the concept of symmetry found in the literature of aesthetics is too limited to be of value in design analysis. In general this literature, includ-

ing that in the field of philosophy and psychology as well as in that of pure and applied art, is dominated by the attempt to evaluate, a process which is irrelevant to the anthropological approach. The archaeologist may study design either as a criterion for identifying pottery types and as a means of following contacts of peoples through the spread of art styles, or as a cultural trait, in which instance he will consider such questions as what characteristics are common to the decorative art of all people, what features are most subject to change, how a style develops, in what ways artistic standards vary from time to time, and how new elements are assimilated. In either case, his individual tastes and those of his time have no bearing on his investigation, and his first problem is to recognize fundamental properties and to define them unequivocally. For the most part, archaeologists have previously centered attention on elements, motifs, or symbols and on methods of composition. These are particular features, treated descriptively. In contrast, symmetry permits classification by general, basic categories. The six different pottery styles which were used to test the significance of symmetry in design history exhibited a marked degree of variability in this property and at the same time showed its direct relation to design structure. The effect of symmetry on the less well defined characteristics of balance, rhythm, and dynamic quality was demonstrated by experimental constructions. Thus it has become apparent that symmetry is one of the fundamental features of formal design and that it lends itself particularly well to exact classification.

The effective utilization of the facilities of the Ceramic Technology Project is largely a problem in integration of evidence. We have in the Maya field particular advantages for ceramic studies, and also some handicaps. These can be weighed by comparing conditions with those in the Southwest, where the value of the method was first tested. Maya ceramics offers a richer field for research: first because there is variety and refinement of decorative techniques reflecting the cultural advancement of the people, and second because there was much more extensive trade than in the Southwest, and it is in separating imported from local wares that petrographic methods have proved particularly useful. Our principal unfavorable factor is the difficulty of sampling pottery. Because of the rarity and weathered condition of surface sherds, it has been impossible to plot distribution of types by the economical method of surface survey which has been so fruitful in the Southwest. Also excavations have in many instances been in the nature of tests in widely separated regions from which it is difficult to make a well rounded historical reconstruction. For example, we may establish a sequence from a carefully excavated site, but as long as our knowledge of the ceramics of the surrounding area is blank, there is insufficient basis for distinguishing local from imported wares. Nor can we judge whether changes reflect indigenous developments or result from the introduction of new ideas or from replacement of populations. These circumstances have tended to reduce the work of the project to routine identifications for purposes of classification and record, thus supplying a necessary foundation for future investigations at the risk of wasting effort on details which may prove eventually to have no general archaeological significance.

A second circumstance seemingly unfavorable to technological work in the Maya area is the wide distribution of two commonly used tempering materials, limestone in the Peten lowlands and the Yucatan Peninsula, and volcanic ash in the highlands. Small unrelated collections have

probably exaggerated the handicap of this condition, as is shown by the fact that recent analyses of a well selected sample of Miraflores pottery showed a number of distinct varieties of ash, each associated with particular stylistic types. The possibilities of identifying material from different sources are therefore much better than they at first appeared; consequently our principal problem is one of sampling.

The studies of the past few years have demonstrated the advantages of extending the scope of the project and have suggested means of avoiding the limitations imposed by detached collections. Intensive study of archaeologically important wares or types best reveals trade relations and the spread of ceramic traits, and also most effectively illustrates aesthetic standards. In such studies we are not dependent on small sherd lots from single excavations, but can bring together evidence from collections of the entire area. Usulutan, a well distributed ware of the early horizon, has been chosen to trace the spread of a decorative technique and to locate centers of manufacture and the extent of their trade. There are also groups of types which would repay more detailed review in this way; for example, certain polychromes of the Peten and the fine orange types of the Gulf coast. A second method of approach is by cultural regions, summarizing, comparing, and interpreting all available data. This would give a clearer picture of the similarities and differences of regions and show which among a complex of traits had the widest influence and which were specialized and restricted. It would also enable us to weigh the influence of environmental factors, the effect of natural resources on ceramic development. Both types of investigation would require close correlation of technical and stylistic evidence and would have as their primary aim the understanding of trends of development and the interactions of cultures as reflected by pottery. Finally, it is our responsibility to make available to the archaeologist that part of our experience in ceramic analysis which would be useful to him. An archaeological ceramics handbook is therefore being planned.

Early Cultures of Southwestern United States

E. H. Morris

The past year was spent by Mr. Morris in desk work leading toward the completion of three reports bearing upon Southwestern archaeology.

The first report presents the results of three seasons of excavation near Durango, Colorado, in sites dating from the Anasazi periods Basket Maker II and III. Formerly it was believed that the people of Basket Maker II had no architecture more elaborate than that exemplified by their storage and burial cists. Now it would appear probable that the failure to find remains of their dwellings in most localities within the Basket Maker domain is due to the fact that conditions were not favorable for their preservation, rather than to original absence. Near Durango the reverse was true. Built on terraces cut into a steep hillside, the habitations became deeply buried under detritus from the slope above and remained easily identifiable until the time of excavation. The principal contribution of the Durango report will be a description of Anasazi domestic architecture in the third century of the Christian era.

The second report is an intensive study of Anasazi cross-woven sandals. These sandals were finger-woven without the aid of a loom. The more elaborate specimens reveal some of the most complicated hand weaving that the world has seen at any time or place. As a generality, the upper surface bears well executed designs in color, but on the nether surface the decora-

tion is in raised patterns usually produced by devious knotting of the weft strands. In some of the earliest and most involved examples, however, a like effect was produced by the use of secondary warps and wefts so manipulated that a two-ply fabric was produced. Owing to the quantity of discarded footgear taken from dry refuse in Arizona rock shelters, the art of the Anasazi sandal makers is represented by more examples than any other early American art in perishable media. Material in hand will permit the tracing of the life history of this art for roughly a thousand years—from early in the third century to about 1250.

The third report is a detailed analysis and description of a group of sashes, presumably ceremonial, exhumed by a Carnegie Institution expedition in a dry shelter in northeastern Arizona. Despite their great age—timber dates from the shelter range from A.D. 473 to 478—the sashes are as perfectly preserved as if made but yesterday. They range in width from 1½ to 3 inches and in length from 6 to 9 feet. Some are white, some are brown, and others have a white ground patterned in brown. The white is dog hair, the brown an animal hair thus far unidentified. Flat-braided from as many as 119 two-ply strands throughout most of their length, toward the ends they are broken down into a series of long square-braided fringes that fray out into tassels of individual strands at the extremities. The fringes of one are strung with beads of *Olivella* shell. The study of the construction of these superlative textiles throws additional light on the virtuosity of Anasazi weavers of the fifth century.

Social Anthropological Research

Robert Redfield and Associates

The activities of the group working in this field during the period under review took the form, for the most part, of publication or of preparation of manuscripts for publication. A principal exception was the work accomplished by Dr. John Gillin of Duke University, who returned in the summer of 1946 to San Luis Jilotepeque, in eastern Guatemala, to resume his studies of the Chorti. He has taken with him Mr. William Davidson, a student who will make personality studies among the Indians. In March, Calixta Guiteras Holmes returned to Chiapas, Mexico, to continue work in the area, and especially in the hitherto unstudied Tzotzil town of San Pablo Chalchihuitan. Ricardo Pozas Arciniegas also returned to Chiapas to continue his study, especially of Chamula, during the months of December 1945 and January 1946. These Mexican field investigations are under the direction of Dr. Tax.

Dr. Tax, while devoting half his time to teaching at the University of Chicago, carried forward various research and publication projects. In the autumn of 1945, he delivered a series of eight lectures on the Indian cultures of highland Guatemala, the materials of which constitute a part of his book on the Panajachel Indian community. During the summer of 1946 he will devote most of his time to completion of that work, which should be ready for publication by the end of the year.

During the year the first series of eight manuscripts of the "Microfilm Collection of Manuscripts on Middle American Cultural Anthropology" was published and distributed. Although the University of Chicago Library is actually publishing the series, and funds for editing the manuscripts were supplied by the Viking Fund, this microfilm project had its origin in the ethnological work of Carnegie Institution. Under the editorship of Dr. Tax, who consulted with Dr. Alfonso Caso in the inception of the project, there has been created a continuing library of ethnological and

linguistic materials which any individual or institution can buy as a series of books is bought. This form of publication brings into quick circulation among scholars the results of field work in relatively unelaborated form, so that specialists may study not only the investigator's conclusions, but also the primary data, and may do so without having to wait for more formal publication. The project is also designed to improve methods of research. In some other sciences, the report of the results of an experiment can be verified by repeating the experiment; but field research in the social sciences cannot usually be repeated. The scholar must therefore, in most cases, accept or reject interpretations and conclusions on the basis of what the field worker chooses to publish. The printing of all field materials in as nearly their original form as possible is impracticable; not only is it costly, but since only a few specialists would ever read the original materials, it is wasteful. Thus, the reporter publishes only what he judges is pertinent to his thesis, and the reader must take on faith the writer's competence to present a fair account. But now the Microfilm Collection makes available the full field observations, even though in their original rough form.

All eight of the items of the first series now published contain notes on investigations in which the Institution has had a hand. They include J. S. Lincoln's posthumous report on the study of the Ixil Indians, which was partly financed through the Institution; Melvin M. Tumin's study of San Luis Jilotepeque, which was done with the advice of the Institution staff; Dr. Redfield's notes on Agua Escondida and on San Antonio Palopó; Mr. Villa's notes on Oxchuc; and three of the studies resulting from the Chiapas expeditions directed by Dr. Tax, two by Fernando Cámara Barbachano and one by Calixta Guiteras Holmes.

The response to the Microfilm Collection on the part of other research institutions and libraries has exceeded expectations. Within a few weeks after the preliminary announcement, more than a dozen subscriptions had been received.

Mr. Villa began the large task of writing up the results of the studies of the Tzeltal and Tzotzil Indians which he has carried on for several years. To do this he came to Chicago and remained there during the year. He first studied and annotated the great body of ethnographic materials at the University of Chicago (over 6000 pages), which were obtained from Indians of these two groups by students who worked under Dr. Tax. This done, he began the preparation of a book that will present the life of the Tzeltal community of Oxchuc and, with this as the central point of reference, the comparative ethnology of the entire Tzeltal-Tzotzil area of Chiapas.

Mr. Villa's work was interrupted by an accident in which his leg was broken, but two chapters and certain tables and maps were finished. In the course of his study, he became especially interested in problems of kinship terminology and practice and began work on a special monograph on this subject. Restudy of the kinship system characterizing the ancient Maya, and those of the Lacandones, the Tzeltal, and the Tzotzil of recent times, led him to the conclusion that the systems of totemic clans found among the Lacandones is but a local variant of a social and kinship system derived from a system general in the Maya area in pre-Hispanic times and represented also in the communities recently studied in the field by Mr. Villa. The development of this investigation should clarify our understanding of the form of social structure which anciently prevailed among the Maya.

During the year the results of the food survey of Guatemala, which was conducted by Srs. Goubaud, Rosales, and Pop under the direction of Dr. Tax in 1943–1945, were put in manuscript form. They are to be published by the new National Indian Institute of Guatemala, of which Mr. Goubaud is the director.

Also during the year, Sr. Rosales, who is now studying in Mexico City while continuing his work for the Institution on part time, completed his second volume on San Pedro Laguna. The first volume, on the technology of the community, is being prepared for publication by the National Indian Institute, which will probably also publish the subsequent volumes. The second, on the economy of San Pedro, was prepared by Sr. Rosales with the assistance of Sr. Julio de la Fuente, the Mexican anthropologist, who, it is expected, will continue to collaborate with Sr. Rosales in subsequent volumes. The third will contain an account of the social organization of the community, including the familial, local, political, and religious organizations; the fourth will be a study of social control, and will include the large body of court records obtained over several years in San Pedro. The last volume will be a statement of the mental life, the folklore, and beliefs of the Indians.

The manuscript of Mr. Oliver LaFarge on the Indians of Santa Eulalia was edited for publication under the direction of the Institution staff and Dr. Melvin M. Tumin. It is being published by the University of Chicago Press.

History of Yucatan

F. V. Scholes, R. L. Roys, E. B. Adams, R. S. Chamberlain

The volume on the history of the Chontal Indians of Acalan-Tixchel, on which Messrs. Scholes and Roys have collaborated, was completed during the past year. The work is now in press.

During the year Mr. Scholes and Miss Adams have also carried forward the documentary research for the general history of Yucatan and its environs in colonial times. Although the greater part of this work will deal with northern Yucatan, sections of it will also be devoted to developments in the interior of the peninsula and the many efforts to pacify the unconquered Indians in the regions bordering on the frontiers of Tabasco, Chiapas, and Verapaz. The documentary sources, printed and manuscript, dealing with the Indians of these frontier districts are numerous and have not been fully exploited by historians and ethnologists. In the present report, it may be of interest to give advance notice of an unpublished manuscript on the history of Verapaz, Guatemala, and adjoining areas compiled by Don Martín Alfonso de Tovilla, who served as *alcalde mayor* of Verapaz in the early 1630's. A complete account of this work, with translations of its more important sections, is being prepared for publication by Mr. Scholes and Miss Adams.

Tovilla was appointed to the office of alcalde mayor of Verapaz on December 18, 1629. The following year he sailed with the fleet for America, taking passage on one of the ships bound for Honduras, and finally reached Coban, the administrative center of Verapaz, early in 1631. Fray Francisco Ximénez (*Historia de la provincia de San Vicente de Chiapa y Guatemala,* bk. 4, ch. 68) mentions Tovilla but tells little about his activities as alcalde mayor. From Tovilla's own account we learn that he had a keen interest in the history and customs of the Indians and made some effort to pacify certain groups of Manche Chol on the frontiers of Verapaz. Little is known concerning his later career. His treatise entitled *Relación his-*

tórica dyscreptiva de las provincias de la Verapaz y de la del Manche de el Reyno de Guatemala . . . is dated at Coban, May 17, 1635.

The *Relación* is divided into two books, the first containing 26 chapters, and the second, 14 chapters. Extensive sections, especially those dealing with the early history of Verapaz, are taken largely from Remesal and have little merit. On the other hand, the chapters dealing with Tovilla's own activities and the descriptions of native life recorded in various parts of the work have genuine value.

Book 1, chapters 1–6 record the story of Tovilla's journey to America in 1630–1631. Here we find an interesting account of the long voyage to the West Indies, a description of the city of Trujillo in Honduras, and the narrative of the author's trip from Trujillo to Coban by way of Santo Tomás de Castillo, Golfo Dulce, and the Río Polochic. After describing his arrival in Coban, the author interrupts the account of his own activities to give a lengthy statement concerning the early history of Verapaz (bk. 1, chs. 7–23). As already noted, this account is based largely on Remesal. In chapter 22, however, he includes the text of ordinances for the government of the Indians of Coban formulated in 1625 by Juan Maldonado de Paz, *oidor* of Guatemala. This document throws light on native life and customs. In chapter 23 the author gives a brief account of "the fruits of the land and the festivities which the Indians observe."

On arriving in Coban, Tovilla obtained information from the missionaries concerning the Manche Chol and other Indian groups on the frontiers of Verapaz. Missionary activity among these Indians was begun in 1603, and considerable progress was made during the succeeding quarter-century. But conditions in the Manche district were far from stable, and Tovilla formed plans for the founding of a new settlement in that region as a means of imposing a greater measure of Spanish control. In March 1631 he went to Guatemala City to obtain authorization from the superior governmental officials for the enterprise. In book 1, chapters 24–27 we have a record of the events of this journey, a brief account of Guatemala City, and the texts of the orders issued by the captain general of Guatemala naming Tovilla commander of the proposed expedition to the Manche country.

In April–May 1631 Tovilla and a small group of soldiers advanced into the interior from Coban. They were accompanied by Fray Francisco Moran, prior of the Coban convent. On May 17 Tovilla founded a settlement named Toro de Acuña near the site of San Miguel Manche. Soon thereafter the alcalde mayor returned to Coban (bk. 1, chs. 27–28; bk. 2, chs. 1–6).

During succeeding months Tovilla made a visitation of his province and adjacent areas. His account of this trip (bk. 2, chs. 7–12) includes data concerning various Indian groups on the northern frontier, an interesting account of the Lacandon, and also information on the Quiche. Toward the end of 1631 it became apparent that the new settlement of Toro de Acuña would need reinforcement, for the region was subject to attack by the Itza. After considerable delay the captain general of Guatemala authorized Tovilla to take necessary measures. Before Tovilla's plans could be carried out, however, the Itza raided the frontier, forcing the soldiers and Father Moran to withdraw in haste to Cahabon. Although Tovilla again appealed to the captain general, the latter refused to act until the matter was referred to Spain for decision. This apparently occurred in 1633, and it seems likely that Ximénez' account of a Manche rebellion in that year actually refers to these develop-

ments. Tovilla's account of Verapaz ends with this episode. The last chapters of the *Relación* contain a description of the coasts and ports of America (bk. 2, chs. 13–14).

As a historical source Tovilla's report is interesting chiefly because it records certain facts hitherto unknown concerning the Manche missions. The ethnological data scattered through the *Relación* have even greater significance. For purposes of illustration the following quotations are taken from the author's account of the customs of the Manche Chol:

> These Indians of Manche have many idols. . . . Three are their principal gods, which they call Man. Canam. Chuen exchel. When [the Indians] perform sacrifice and celebrate feasts to them they set up a large bower (*enramada*) in an arroyo, and they paint themselves, the married men red and the youths black. They set up an altar in which the idol is placed. Then comes the priest, whom they call *acchu*. He wears painted vestiments made of the bark of trees. On the sides of the altar are placed two wooden [an illegible word here] with shallow dishes full of incense. In another dish the priest collects the blood which all draw in sacrifice from their ears, arms, and thighs, and he offers it to the idol. . . . Then all leave together, and in another place they become intoxicated with a very strong drink called *chicha*. Those who serve this drink are all maidens, adorned with feathers, strings of beads, and garlands. They are accustomed to spend two or three days in this drunkenness.

In view of the fact that other early writers state that the Manche Chol did not have idols, the foregoing passage has considerable interest. The names of the "three principal gods" are recorded exactly as they stand in the manuscript. It may be noted in passing that Moran's dictionary of Chol gives the term Mam for idol. Thompson (1938, p. 599) has called attention to another reference to ceremonial intoxication among the Manche Chol.

Thompson has noted that other early accounts contain no mention of a Chol calendar, "except that the new year celebration at Dolores was called *Chuntal Cutaz*" (*ibid.*). Tovilla describes the Manche calendar as follows:

> [The Manche] divide the year into eighteen months of twenty days each, and the twenty days all have their name. . . . The month is called *uinal*. The twenty days are divided into four divisions of five days each, and the first four days of these four divisions change position annually to begin the months. According to what [the Indians] say, [these four first days] are those which direct the way (*toman el camino*) and bear the burden of the month (*cargan el mes*), changing in turn. These eighteen months comprise 360 days, at the end of which are five which they call [days] of great fasting, days which have no name. With these five days are completed the 365 days [of the year]. The only error I have found in this count is that [the Indians] are ignorant of the leap years. This is not surprising, since for so many years we erred in this until the Church corrected it, adding a day every four years in the month of February because of the six hours by which each year exceeds 365 days. In the count of the Chol these eighteen months end on June 28 . . . and then come the five days of great fast. This lasts until July 3, and it is a vigil of great veneration among them. Thus on July 4 begins the first day of the year according to their count.

From Tovilla's date July 3 one must subtract 10 days to reduce it to Julian. If 21 days are added from the elapsed leap-days, not recorded in the Maya calendar, the new year of the Chol would have fallen on July 14, 1553 (Julian), whereas Bishop Landa gives the start of the Yucatec year, for what can be deduced to have been 1553, as July 16 (Julian).

In view of the discrepancies which occur

in the parts of the Books of Chilam Balam relating to chronology and history, Mr. Roys has undertaken a comparative study of these manuscripts. Although it is evident that they contain many extracts from earlier manuscripts, nearly all of them apparently were compiled between the middle and end of the eighteenth century. Besides being of linguistic value, they serve a double purpose. Not only do they furnish a very considerable amount of ethnological and historical material for the study of the preconquest Maya, but they are also valuable for the colonial history of Yucatan, since they contain an admixture of European ideas and information which help greatly in making an appraisal of the acculturation of the Yucatecan Maya in the eighteenth century.

Some of the ancient lore recorded in these books appears to have been copied verbatim from earlier sources which show little Spanish influence, but much of it is interspersed with explanations, comments, and possibly even alterations by the later compilers. This is not always a defect. Sometimes the copyist explained obscure expressions and statements, which would otherwise be difficult to understand. Only too often, however, the interpolations are confusing.

A large number of the compilers of these manuscripts were more concerned with European lore of the sort found in the contemporary Spanish almanacs than with their own customs and traditions. The Book of Chilam Balam of Ixil, which probably dates from the late eighteenth century, is an excellent example of this tendency. Of its 88 pages, a little more than half contain copies of Maya translations of European material. There is a Catholic calendar, which is not translated, giving the days of each month, together with the epacts and dominical letters. Except for a few church festivals, the saint for each day is named, which was no doubt useful in selecting names for children. Accompanying this calendar is a dissertation in Maya on the European zodiac. Beneath a picture of each sign is the usual information found in European almanacs, such as the day when the sun enters the sign, the number of stars in it, the hours of daylight and darkness, and other information for the guidance of a person born under this sign. To this are added a chart, some tables, and other material on zodiacal anatomy, so that a healer might avoid bleeding any part of the body while the sun is passing through the sign of the zodiac ascribed to that part. Since bloodletting was a traditional remedy among the Maya, it is easy to understand their interest in this matter in colonial times. We also find a diagram and explanation in Maya of the medieval cosmos. The remainder of the part of the book which is European in content consists of Maya translations of sacred history. These are based on Genesis, but they contain a number of details which are not recorded in that book. Additional material of this sort, including passages from a popular Spanish romance dealing with astrology, is to be found in other Books of Chilam Balam, especially those of Kaua and Mani, although the latter two differ from the Ixil in that they contain more of the old native lore. That so much European material was translated into Maya is evidence of the extent to which a large and important element of the native population had become Hispanicized in spite of their ignorance of the Spanish language.

Nearly one-half of the Ixil manuscript is devoted to material which is essentially Maya, but modified by European ideas. Here we find a correlation of nine months of the European calendar with the corresponding Maya days. A similar calendar was adapted by Pío Pérez to the years 1841–1842 and published a century ago

(Stephens, 1843, vol. 1, pp. 449–458), and others occur in most of the Books of Chilam Balam. They contain weather predictions, prognostics of "good" or "bad" days, warnings of sickness and death, and various other portents, some of which are very difficult to translate. There is also a faulty correlation of the Maya uinals, or twenty-day months, with the native day names. At the end of the Ixil manuscript are 27 pages of medical prescriptions. They are ascribed to a Moorish physician, a slave of the Cid Campeador, but they are largely Maya in content, although they contain a sprinkling of European remedies, and a good many names of plants and diseases are given in both Spanish and Maya.

There are only a few pages in the Ixil of material that is purely Maya. A little of this is astrology and the remainder is concerned with Maya chronology. There are two of the so-called calendar wheels, one of which represents an alleged "katun" of 13 years. Apparently this part of the book was copied from an earlier Maya manuscript written in 1701, but the errors strongly suggest that the Ixil copyist did not understand his subject. The inference is that by the last quarter of the eighteenth century many people were losing their former interest in the Maya sciences and historical traditions. This was not yet everywhere the case, however, as we see by comparing the Ixil manuscript with the Book of Chilam Balam of Chumayel, written in 1782. Here, it is true, there are a few translations or paraphrases of Spanish material, but most of the book consists of Maya rituals, catechisms, prophecies, historical narratives, and chronicles, although we find in places some admixture of European ideas. The selection of the material in the Book of Chilam Balam of Tizimin is even more conservative and it contains fewer references to things Spanish, but it was probably composed at least a generation earlier than the Chumayel. The book of medical incantations known as the Ritual of the Bacabs is almost entirely pagan in character, although it was actually written no earlier than 1779.

The last important Book of Chilam Balam is the Kaua, written at about the end of the eighteenth century. It contains medical prescriptions, prophecies, and Maya astrology, and there is a rather unsatisfactory explanation of Maya chronology written in Spanish. A large part of it, however, is devoted to European astronomy and astrology and to the Christian religion.

The conclusion Mr. Roys has drawn from this study is that, valuable as these sources are for the study of Maya civilization, in their present form they come down to us from the hands of writers who were removed by at least two centuries from the Spanish conquest, during which time they were subject in varying degrees to European influences, and the chronological information and historical traditions they present should be used with considerable caution.

Mr. Chamberlain, who served as cultural attaché in the United States Embassy in Guatemala for four years (1941–1945), resumed work as a staff member of the Division on October 1, 1945. His volume on the conquest of Yucatan is now nearing completion. He has also written a large part of a supplementary study dealing with the Adelantado Francisco de Montejo as governor of Higueras-Honduras, 1535–1539. Two shorter papers, one relating to the early history of the town of San Miguel in southern Salvador and the other to the government of Montejo in Chiapas, should be ready for press in the autumn of 1946.

History of Science

George Sarton

Introduction to the history of science. Most of Dr. Sarton's time was devoted to the final revision of the manuscript of volume III and to reading proof. All the galleys of the main part of the work have been read, no less than 760, plus 478 page proofs; the latter have been indexed. There remain to be prepared the preface, table of contents, general bibliography, addenda, general index, Greek index, Chinese index. The main index will include from 40,000 to 50,000 cards; when every one is written it will be necessary to re-examine them in order to unify the index as much as possible, and to remove duplications and ambiguities.

Editing of Isis. Three numbers only have appeared (nos. 102–104), constituting the last quarter of volume 35 and the first half of volume 36. These three numbers include 20 main articles, 33 notes, 33 reviews, 794 bibliographic items, 6 plates, and 27 figures. Editorial work is continued by Dr. Sarton and Dr. Pogo, and a large amount of manuscript is ready for publication as soon as circumstances permit.

To these three numbers may be added no. 84, which was printed in Bruges and was ready to be mailed at the time of the German invasion of Belgium. It reached the members of the History of Science Society in the fall of 1945. It is a volume of 314 pages with 2 plates and 5 figures, including 8 main articles, 3 notes, 34 reviews, and 780 bibliographic items. Volume 32 of *Isis* and volumes 8 and 9 of *Osiris* were also in various stages of printing at the time of the German invasion. It is hoped that the first half of volume 32 (no. 85) of *Isis* and the whole of volume 8 of *Osiris* may soon be issued.

Ancient science down to Epicuros. Seven chapters are completed, telling the story down to Pythagoras, but the project is suspended until volume III of the *Introduction* is completely proofread.

Publications

Margaret W. Harrison

Album of Maya architecture (Publication 558), by Tatiana Proskouriakoff, has been completely printed, but even as the difficulties of wartime printing long delayed that stage of the production, so those of the postwar period have delayed the finishing. The book now awaits binding.

The manuscript of *Acalan-Tixchel: a contribution to the history and ethnography of the Maya Indians of southwestern Campeche* (Publication 560), under the joint authorship of France V. Scholes and Ralph L. Roys, is now in press. This volume, the second in a series of historical studies of which Mr. Roys' *Indian background of colonial Yucatan* (Publication 548) is the first, contains a facsimile of the Chontal Text, the only known existing document written in the Chontal language and one of the most important sources for Maya history and ethnology.

Excavations at Kaminaljuyu, Guatemala (Publication 561), by A. V. Kidder, J. D. Jennings, and E. M. Shook, with technological notes by Anna O. Shepard, has progressed as far as page proof. A preview of the report on this site may be had from an article under the same title, written by Dr. Kidder for the October 1945 issue of *American Antiquity.*

Textiles of highland Guatemala (Publication 567), by Lila M. O'Neale, professor of decorative art at the University of California, Berkeley, has been released and distributed. Miss O'Neale's text, which includes a description of textile materials, equipment, techniques, and design motives, an analysis of garments and accessories, a discussion of the weaver as a

craftsman, and a record of costumes village by village, is very fully illustrated with 75 line drawings by Lucretia Nelson, assistant professor of decorative art, and nearly 60 gravure plates.

A monograph *Plumbate: a Mesoamerican trade ware* (Publication 573), by Anna O. Shepard, is now in press. In the course of her analysis of plumbate ware, Miss Shepard gives considerable attention to a classificatory terminology for vessel shapes and symmetry.

Volume IX of Contributions to American Anthropology and History (Publication 574) opens with J. Eric S. Thompson's *An archaeological reconnaissance in the Cotzumalhuapa region, Escuintla, Guatemala* (Contribution 44), also in press. In addition to examining the historical accounts of Indian tribes on the Pacific coast of Guatemala, the paper offers a comparative study of the sculpture recovered from that area.

Publication of fourteen numbers during the year marked the closing of volume II of Notes on Middle American Archaeology and Ethnology in 1945 and the opening of volume III in 1946. Five of these papers, by Messrs. Morley, Shook, and Thompson, are listed in the bibliography at the end of this report. The remainder came from specialists outside the Institution: *A pyrite mirror from Queretaro, Mexico* (no. 53), by Gordon F. Ekholm; *Informe sobre la existencia de jugadores de pelota mayas en la ceramica escultorica de Jaina* (no. 54), by Salvador Toscano; *Un sello cilindrico con barras y puntos* (no. 55) and *Mausolea in central Veracruz* (no. 59), by Jose Garcia Payon; *Archaeological material from the Club Internacional, El Salvador* (no. 60), by Stanley H. Boggs; *Observations on altar sites in the Quiche region, Guatemala* (no. 62), by Elsie McDougall; *The Tamiahua codices* (no. 64) and *The Malinche of Acacingo, Estado de Mexico* (no. 65), by R. H. Barlow; and *Three Zapotec stones* (no. 66), by Heinrich Berlin.

Work on Mrs. Harrison's dictionary of archaeological terms progresses slowly. Research to date has shown such conflict in usage as to pose the question of abandoning a dictionary based strictly on historical principles, as at first planned, for one offering a thorough revision of nomenclature that has been in large part fundamentally unsound. Many useful comments and suggestions have come from specialists to whom preliminary definitions have been submitted.

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